Physics/Global Studies 280: Session 14

Plan for This Session

Questions

News

Module 5: Nuclear Weapon Delivery Systems

The Guardian

Fukushima: Japan insists release of 1.3m tonnes of 'treated' water is safe

Neighbouring countries and local fishers express concern as 12th anniversary of nuclear disaster looms

Workers in hazmat suits remove radioactive materials from contaminated water at the Fukushima Daiichi nuclear power plant. Photograph: Hiro Komae/AP

The Guardian

Fukushima: Japan insists release of 1.3m tonnes of 'treated' water is safe

Almost 12 years have passed since the strongest earthquake in Japan's recorded history resulted in a tsunami that killed more than 18,000 people along its north-east coast.

As the country prepares to mark the 11 March anniversary, one of the disaster's most troubling legacies is about to come into full view with the release of more than 1m tonnes of "treated" water from the destroyed Fukushima Daiichi nuclear power plant.

The tsunami knocked out the plant's backup electricity supply, leading to meltdowns in three of its reactors, in the world's worst nuclear accident since Chornobyl 25 years earlier.

…

The discharge, which is due to begin in the spring or summer, will take place in defiance of local fishing communities, who say it will destroy more than a decade of work to rebuild their industry. Neighbouring countries have also voiced opposition.

The government and Tepco claim the environmental and health impacts will be negligible because the treated water will be released gradually after it has been diluted by large amounts of seawater. The International Atomic Energy Agency says nuclear plants around the world use a similar process to dispose of wastewater containing low-level concentrations of tritium and other radionuclides.

The Guardian

Fukushima: Japan insists release of 1.3m tonnes of 'treated' water is safe

The water will be treated and, if necessary, treated again until the concentration of radionuclides other than tritium have fallen below government limits, said Hikaru Kuroda, a Tepco official overseeing the decontamination and decommissioning of Fukushima Daiichi. "By the time the liquid is diluted with seawater, tritium levels will be at less than 1,500 becquerels per litre, or 1/40th of the government standard for discharging water into the environment," he said.

"We will have contaminated water on the site for as long as we have to cool the reactor basements. And we will release the water very slowly to begin with, so we could be looking at something like 20 to 30 years to complete the process."

The Guardian

Fukushima: Japan insists release of 1.3m tonnes of 'treated' water is safe

An aerial view shows some of the storage tanks for treated water at the tsunami-crippled Fukushima Daiichi nuclear power plant. Photograph: Kyodo/Reuters

Module 5: Delivery Systems

Part 1: Overview of nuclear weapon delivery methods

Part 2: Aircraft

Part 3: Cruise missiles

Part 4: Ballistic missiles

Part 5: Technical and operational aspects

Part 6: Nuclear command and control

Part 1: Overview

Basic Propulsion Mechanisms

- None
  (examples: mines, depth charges)
- Explosives
  (example: artillery shell)
- Propellers
  (example: torpedo, speeds ~ 50 mph)
- Jet engines
  (example: bomber, speeds ~ 600 mph)
- Rocket motor
  (example: missile, speeds ~ 18,000 mph)
- Unconventional
  (examples: barge, boat, Ryder truck, backpack, shipping container)

Examples of Weapon Delivery Methods

Air-breathing vehicles —

- Aircrafts (manned)
- Cruise missiles (unmanned aircraft)

Rocket-propelled vehicles —

- Land-based ballistic missiles
- Submarine-based ballistic missiles
- [Surface ship-based ballistic missiles]*
- [Space-based ballistic missiles]*
- Short range rockets (no guidance)

Other —

- Artillery/howitzers
- Land mines
- Torpedoes

* Never deployed by US or USSR/Russia for nuclear weapons

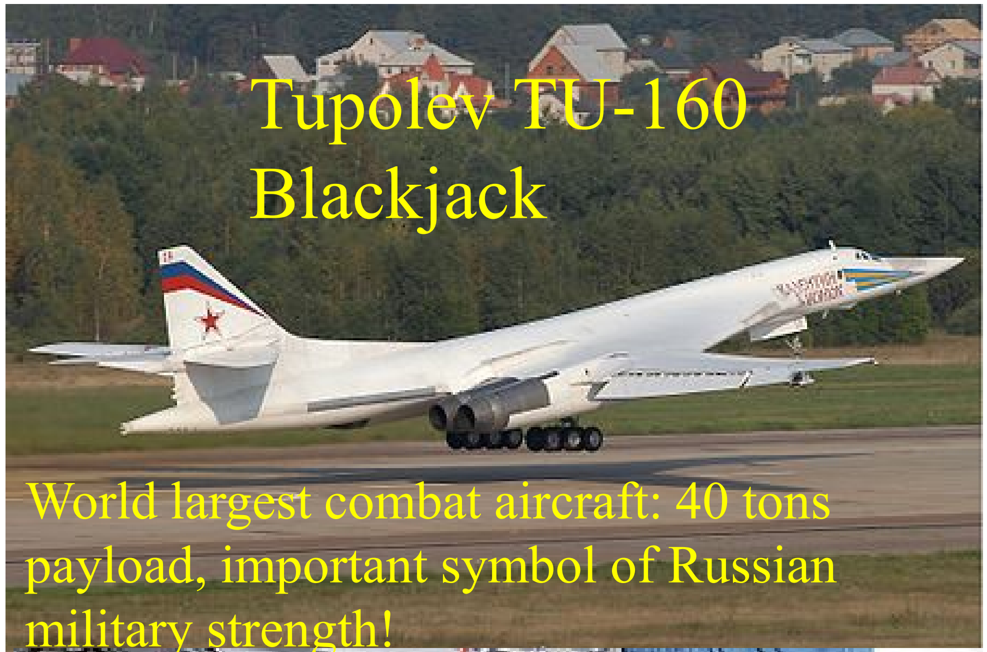
Important Attributes of Delivery Systems

- Range
- Speed
- Accuracy
- Recallability
- Reliability
- Payload/throw-weight
- Ability to penetrate defenses
- Survivability (at deployment base)
- Capital and operational costs
- Safety

Air-Breathing Vehicles

Aircraft (manned) —

- Long-range (“heavy”) bombers
  (examples: Bear, Blackjack, B52, B-1, B-2)
- Intermediate-range bombers
  (examples: B-29, FB-111, …)
- Tactical aircraft
  (examples: F-16, F-18, F-22, …)



Cruise missiles (unmanned) —

- Air-launched cruise missiles (ALCMs)
- Sea-launched cruise missiles (SLCMs)
- Ground-launched cruise missiles (GLCMs)

Rocket-Powered Vehicles

Land-based ballistic missiles —

- Intercontinental-range ballistic missiles (ICBMs)
- Shorter-range ballistic missiles

Sea-based ballistic Missiles —

- Submarine-launched ballistic missiles (SLBMs)
- Surface-ship-launched ballistic missiles

Historical Examples of Other Nuclear Weapon Delivery Methods

Nuclear artillery shells:

- 16” naval guns
- 280 mm cannons (howitzer)

"Atomic Annie" 1953: 15-kt projectile to range of 17 miles

Operation Upshot/Knothole (1953)

Davy Crocket Nuclear Bazooka

- 76 lb., 10–250 t yield, 1.2–2.5 mile range
- Deployed 1961–1971; 2,100 produced

Atomic Demolition Munitions (ADMs)

Carried by back pack, 0.01 kt yield?

Nuclear-armed torpedoes

The U.S. Cold-War Strategic “Triad” – 1

Initially US nuclear weapons delivery systems were developed without an overall coherent plan, in the —

- Truman administration
- Eisenhower administration

Robert McNamara as President Kennedy’s Secretary of Defense changed this:

- Survivable basing
- Secure command and control
- Determine how much is enough by calculation!

    Concluded 400 ‘effective’ megatons (EMT) would be “enough”

- The need to organize the roles for the USAF and the USN defined the “Triad” paradigm
- Established the SIOP (Single Integrated Operational Plan) for targeting

The U.S. Cold-War Strategic "Triad" – 2

Strategic nuclear delivery vehicles (SNDVs) —

The definition of "strategic" nuclear weapons was important for arms control but was controversial during the Cold War: the Soviet Union wanted to count weapons on its periphery whereas the U.S. did not want to count these:

- Systems with intercontinental range (U.S. def.)
- Systems able to strike directly the homeland of the adversary (Soviet def.)

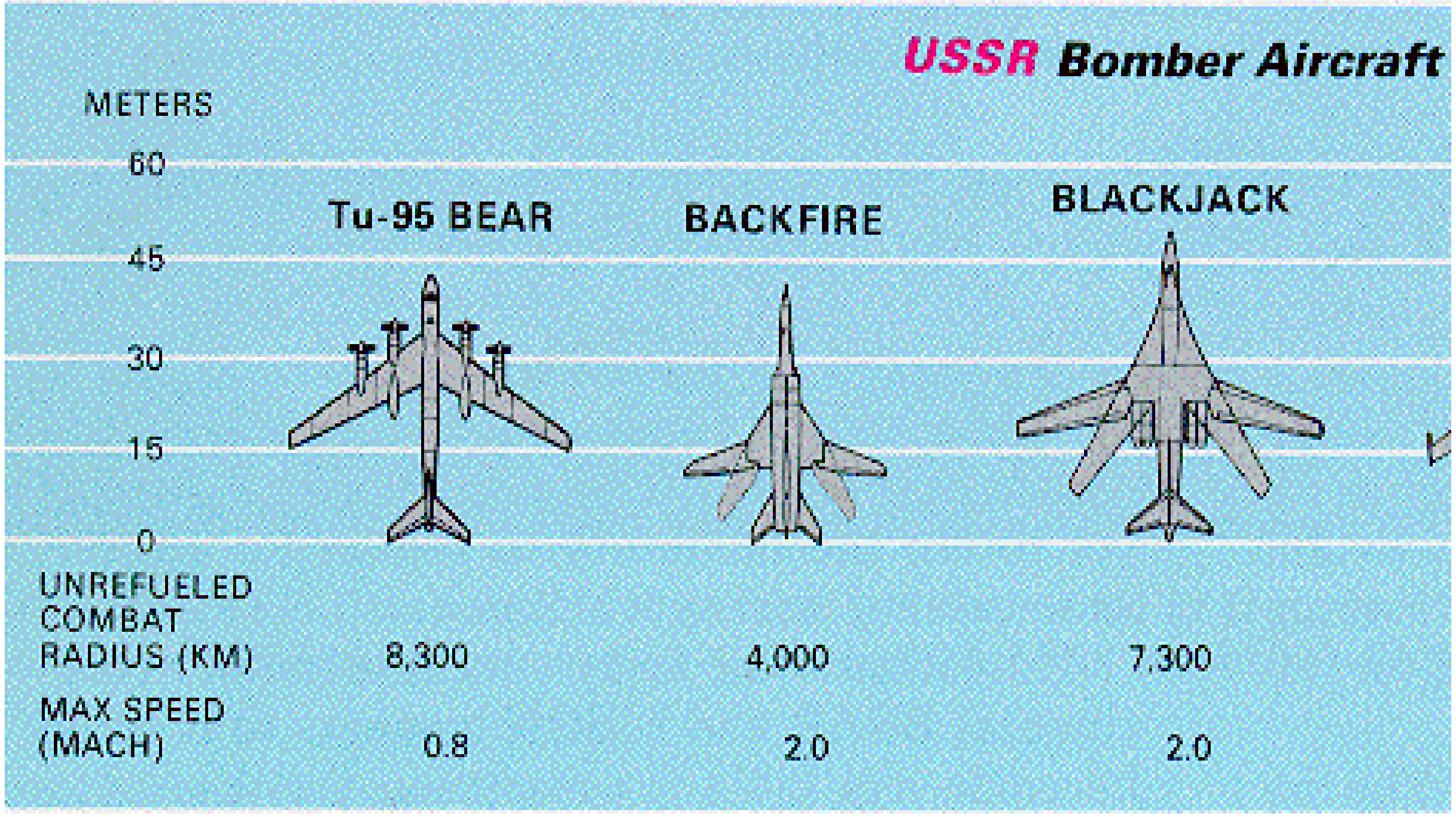
Systems in the Triad —

- Intercontinental-range bombers
- Intercontinental-range ballistic missiles (ICBMs)
- Submarine-launched ballistic missiles (SLBMs)

Module 5: Nuclear Delivery Systems

Part 2: Aircraft

Examples of Intercontinental Bombers – 1



Tu-95	Tu-22	Tu-160
65	160	16

Examples of Intercontinental Bombers – 2

U.S. B-2 Stealth Bomber

Speed: Mach 0.85

Altitude: 50,000 feet

Range: 7,000 miles
Refuel: 11,500 miles

Possible payloads:
• 16 B83 gravity bombs
• 20 B61 bombs
• 80 500 lb bombs

# of B-2s 20

Currently Deployed U.S. and Russian Bombers

Current US bombers —

- B-52 carrying bombs, or cruise missiles
- B1 carry conventional armament
- B-2 each can carry 16 B83 bombs

Russian bombers* —

- Bear carrying bombs
- Blackjacks carrying bombs

*few are currently operational

Intercontinental Bomber Issues

Evolution of bomber missions —

- High-altitude bombing
- Low-altitude penetration and bombing
- As a stand-off launch platform for Air-launched cruise missiles (ALCMs)

Operational considerations —

- Launch, release to targets, and arming of weapons requires permission from the National Command Authority (NCA) (in the United States, the President or his designated successor)
- Can be recalled until weapons (e.g., bombs, cruise missiles, or air-to-surface ballistic missiles) are dropped or fired from the bomber
- The United States has substantial in-flight refueling capability; other countries have none

Part 3: Cruise Missiles

Introduction to Cruise Missiles – 1 (Important)

Cruise missiles (CMs) are pilotless vehicles powered by jet engines:

- Fly within the atmosphere
- Speeds are subsonic

Although cruise missiles were conceived 60 years ago, CMs did not become important until the late 1970s, when technological advances made them militarily useful. These advances were:

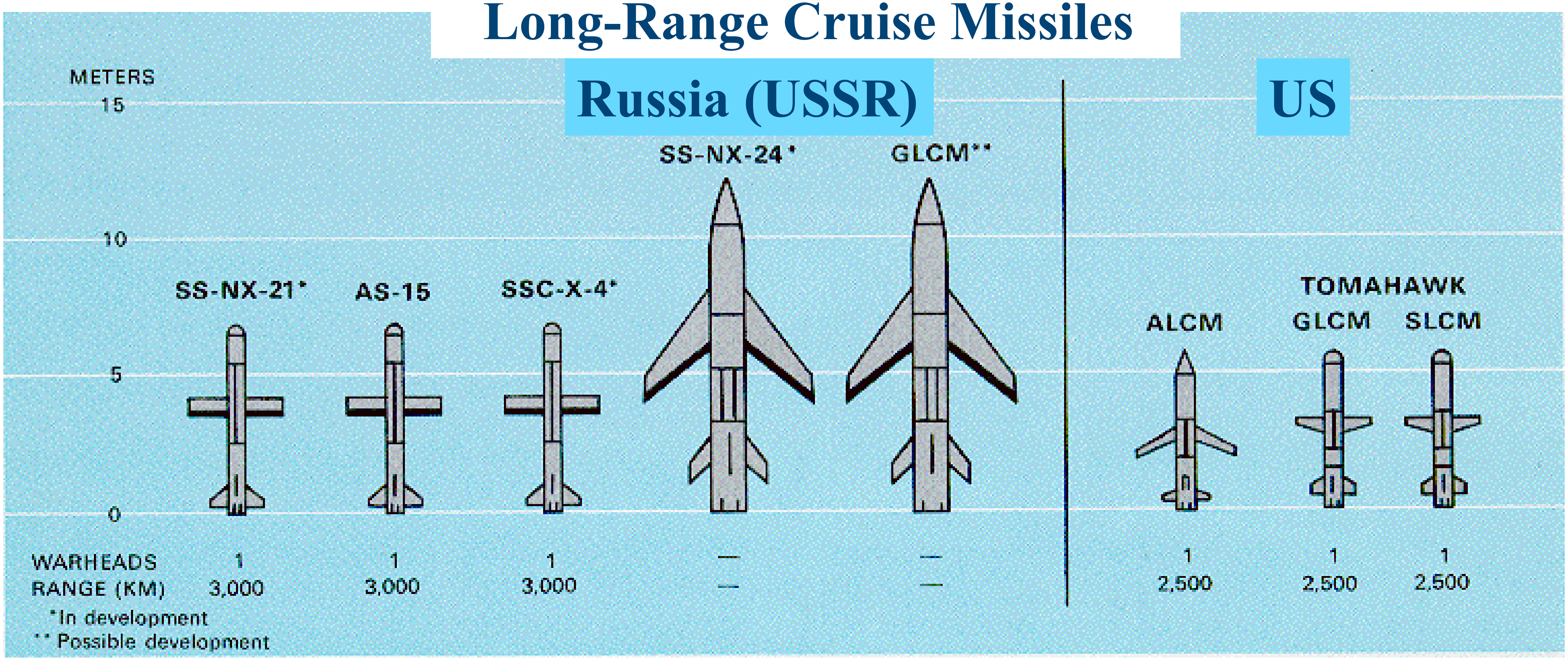
- Smaller and lighter nuclear warheads
- Efficient turbofan engines
- Highly capable miniaturized computers
- GPS, TERCOM (Terrain Contour Matching), and terminal guidance
- “Stealth” airframe technology

Introduction to Cruise Missiles – 2 (Important)

Key properties —

- Small
- Easily stored and launched
- Highly penetrating
- Versatile
- Highly accurate
- Very cheap (about ~ $1 million per copy)

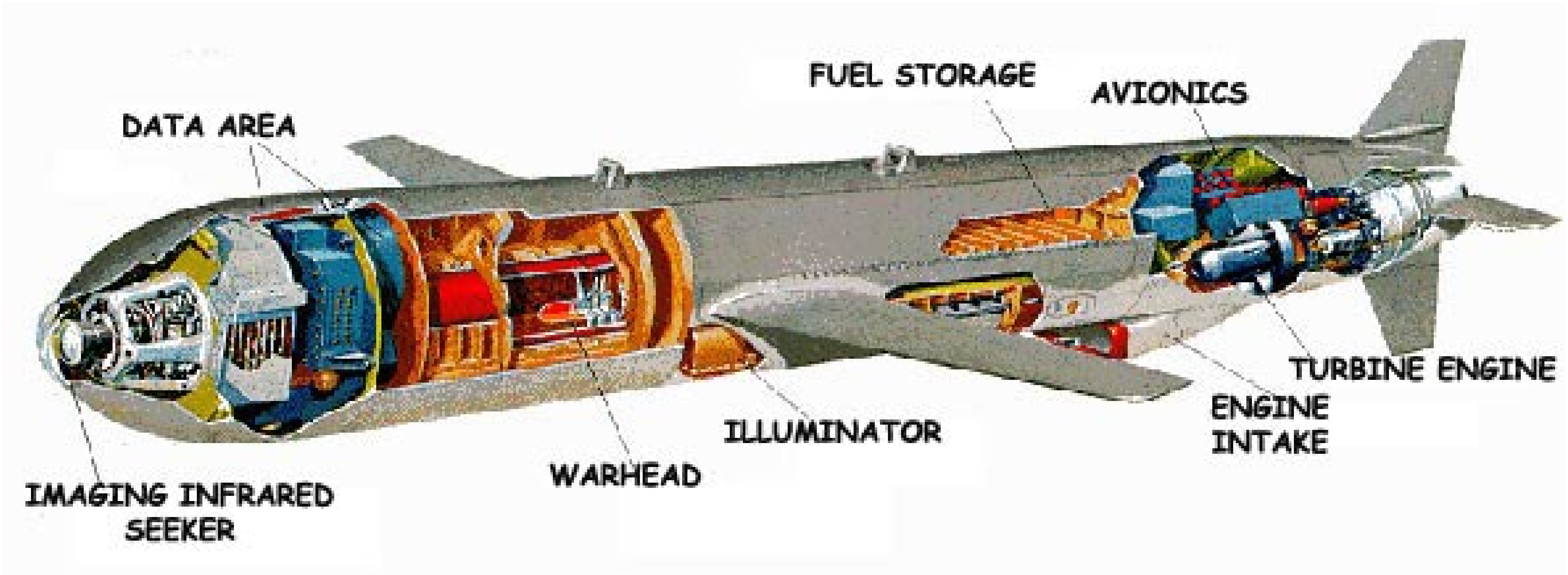
Long-Range Cruise Missiles – 1



range : 1000 – 2000 miles

pay loads : 500 – 1200 lbs

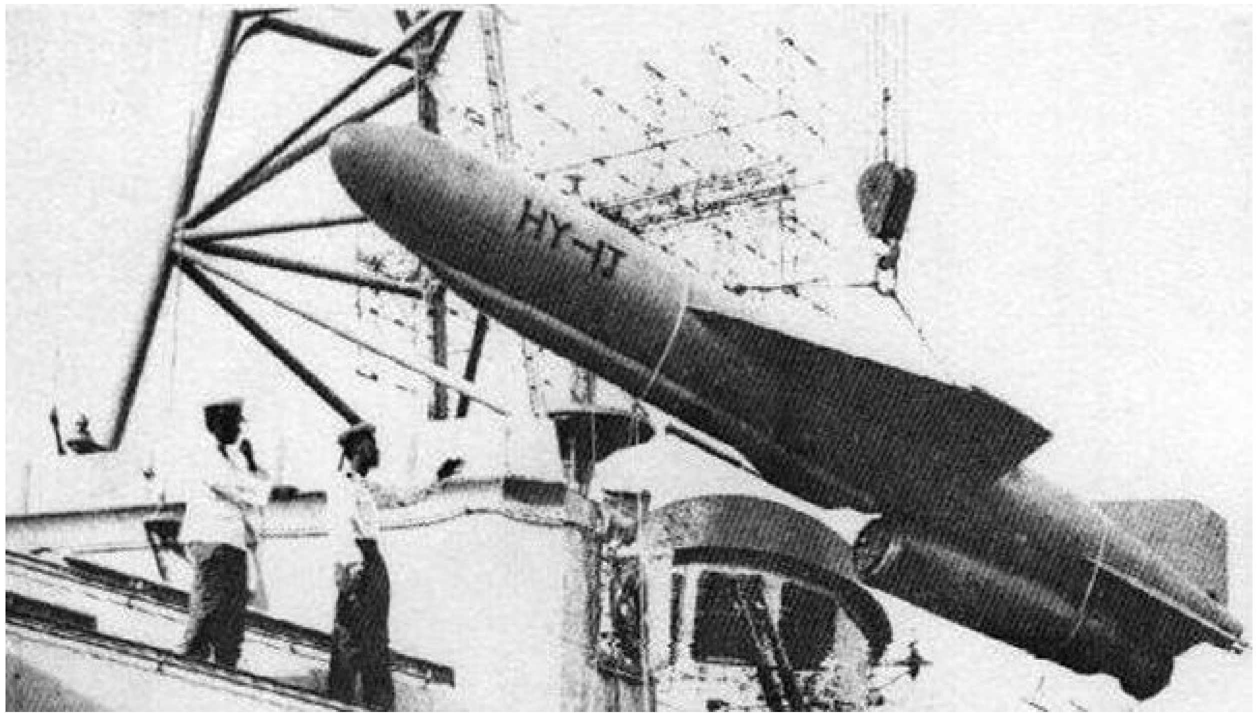
Long-Range Cruise Missiles – 2



Conventionally-Armed Tomahawk Cruise Missile

velocity: 550 mph
pay load: 1000 lbs
range : 1550 miles

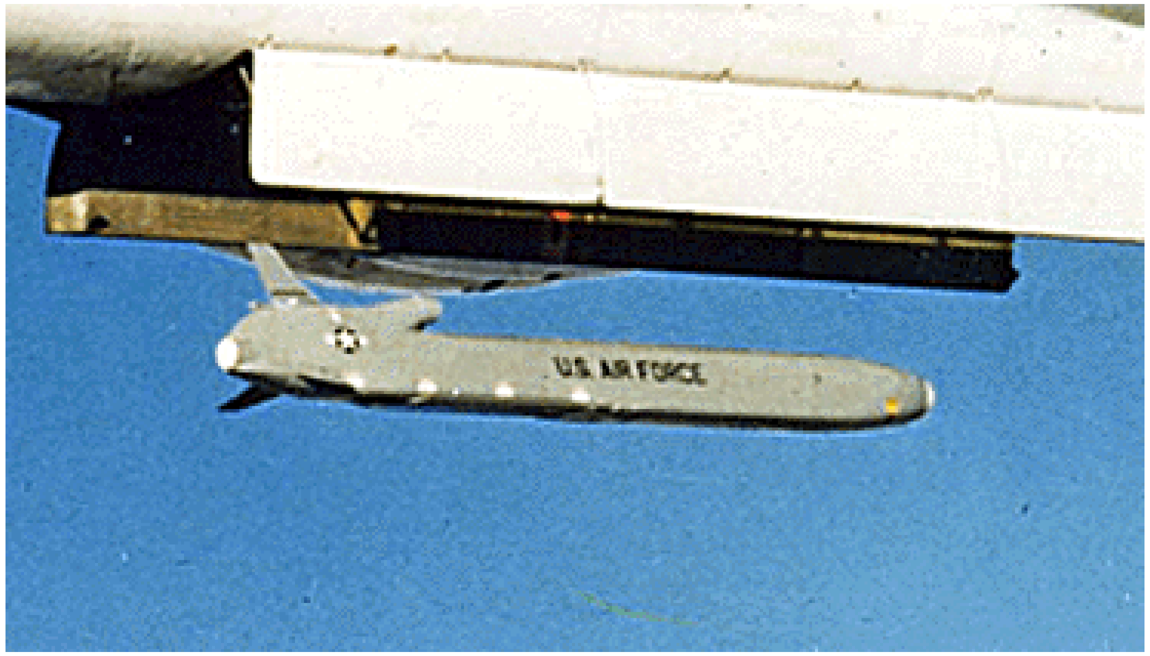
Chinese Silkworm Anti-Ship Cruise Missile



Chinese CSS-C-2 SILKWORM / HY-1 / SY-1 Anti-Ship Cruise Missile

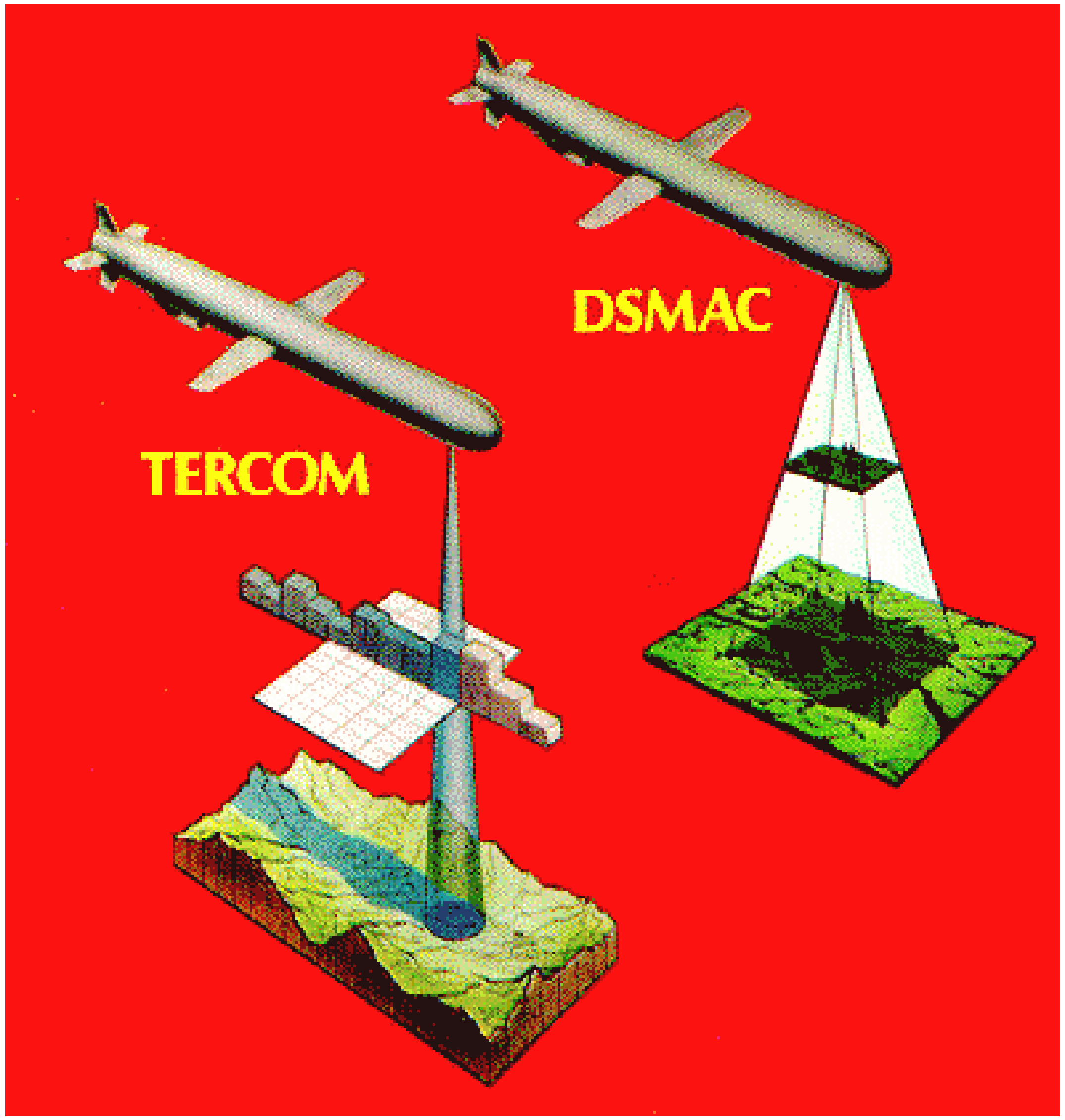
Velocity: 680 mph
payload: 660 lbs
range: 180 miles

Launching Cruise Missiles – 1



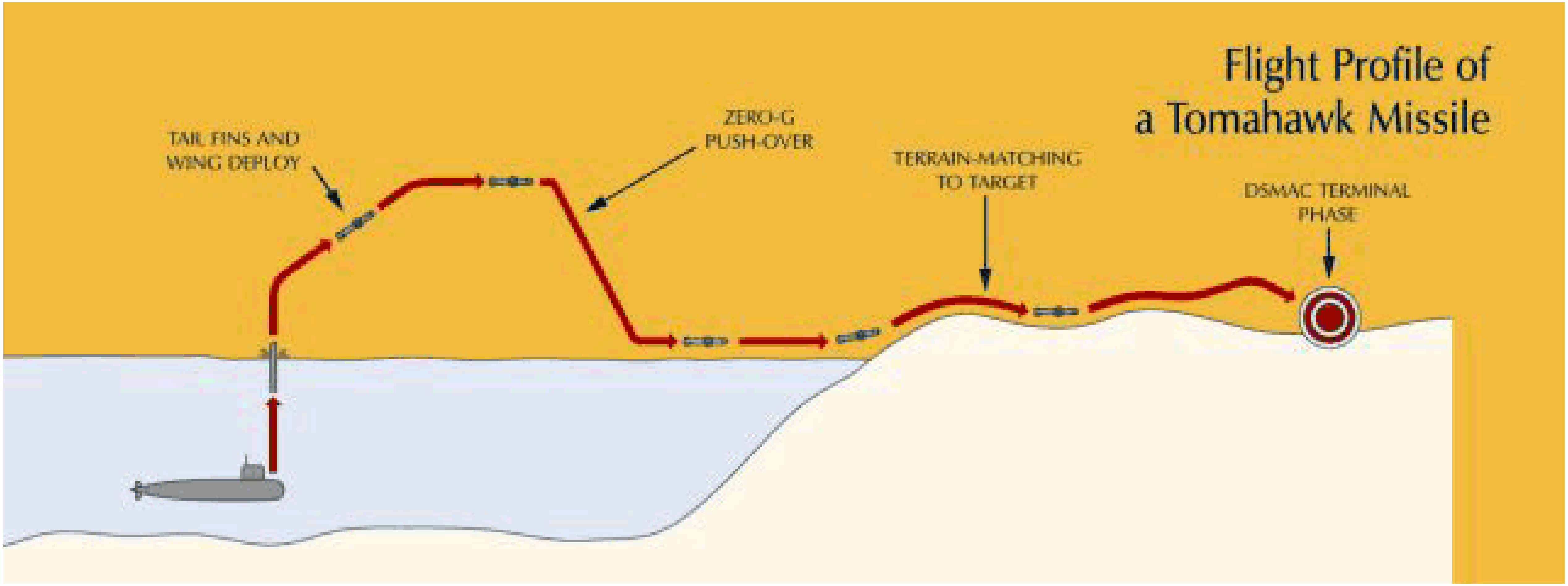
Launching Cruise Missiles – 2

Cruise-Missile Guidance – 1

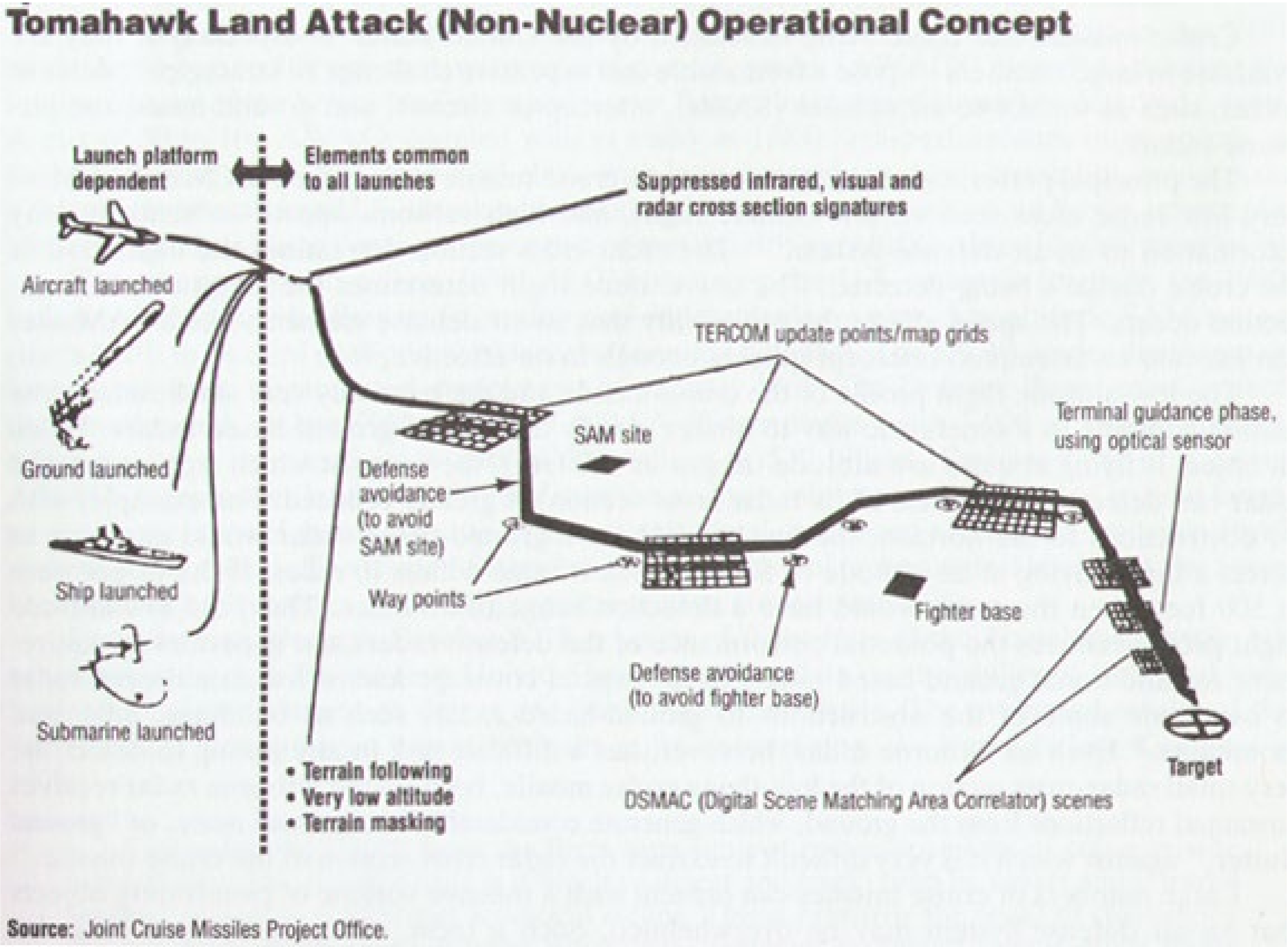


TERCOM: Terrain Contour Matching
DSMAC: Digital Scene Matching Area Correlation

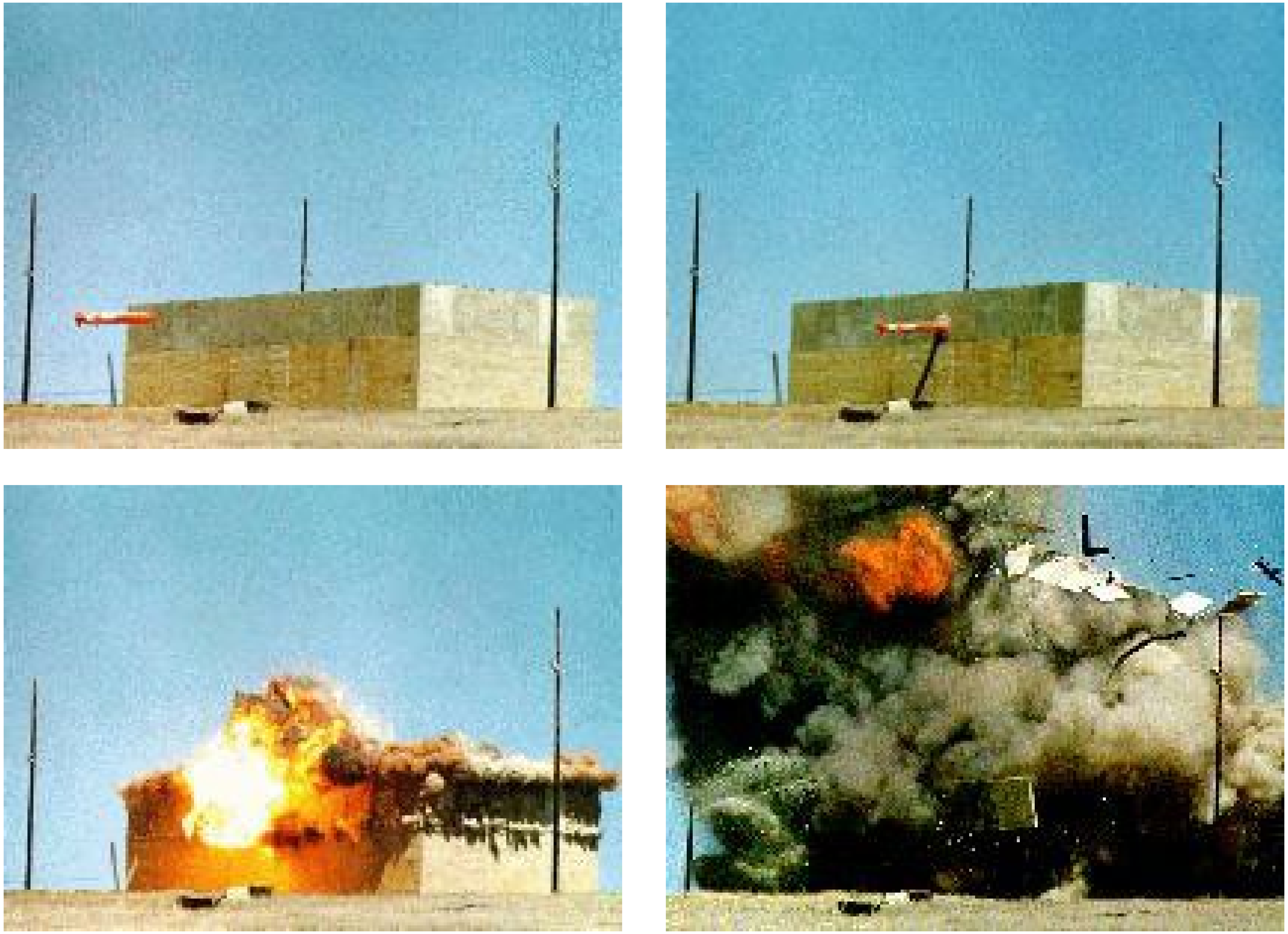
Cruise-Missile Guidance – 2



Cruise-Missile Guidance – 3



Accuracy of Cruise Missiles



Implications of Cruise Missiles – 1

The US developed and deployed CMs without coherent plan that considered the offensive, defensive, and long-range impact of their deployment.

Military history —

- Cruise missiles were the US countermeasure to the heavy Soviet investment in air defenses
- They capitalized on the temporary US lead in this technology
- However, the US is more vulnerable to CMs than Russia due to the proximity of potential targets to the sea shores.

Implications of Cruise Missiles – 2

Implications for U.S. security—

- Very small (hard to find with National Technical Means)
- Can be based almost anywhere (hard to count)
- Dual capable (almost impossible to distinguish nuclear from high-explosive warhead)
- Cheap (can be produced in large numbers)

Several countries could develop a mechanism to launch SRBMs, MRBMs, or land-attack cruise missiles from forward-based ships or other platforms

Physics/Global Studies 280: Session 15

Plan for This Session

News

RE3v2 due Wednesday at 10pm

Module 5: Nuclear Weapon Delivery Systems

The Guardian

IAEA chief qualifies claim that Iran will restore nuclear site monitoring

Head of UN nuclear watchdog had said Tehran agreed to restore equipment and hand over data

Rafael Grossi said 'there are certain things we need to clarify' about what Tehran has agreed to. Photograph: Leonhard Föger/Reuters

The Guardian

IAEA chief qualifies claim that Iran will restore nuclear site monitoring

The head of the UN nuclear weapons inspectorate was forced to qualify some of the claims he made about commitments he had extracted from Iran at the weekend about increasing access to UN inspectors.

At his first press conference on his return from Tehran on Saturday, Rafael Grossi said “yes” when asked if Iran had pledged to restore all the cameras and other surveillance equipment that it had removed from its nuclear-related sites. But at Monday’s press conference he qualified this, saying it required further discussion.
He said there was no agreement at this point on Iran handing over older footage and data taken by cameras and other equipment at the nuclear-related sites, or on future provision of that footage and data. “There are certain things we need to clarify,” he said.

Grossi’s visit to Tehran came ahead of a meeting of the board of the International Atomic Energy Agency this week to discuss a possible further censure of Iran for failure to cooperate with inspectors. If the IAEA board passes a highly critical resolution, Iran might again respond by increasing levels of uranium enrichment and stockpiles that are already far in excess of the limits set in the nuclear deal of 2015.

The Guardian

IAEA chief qualifies claim that Iran will restore nuclear site monitoring

It could also destroy some of the camera footage it has been storing at nuclear sites but not handing to the UN inspectors, a move that would further damage the IAEA's continuity of knowledge about the nuclear programme.

Grossi, a highly experienced Argentinian diplomat, has extracted Iranian promises before to restore the inspectors' previous level of access that European powers and the US feel were not delivered, so in a context of minimal trust the west will want to examine how precise and bankable are the latest set of voluntary commitments that Iran offered Grossi in Tehran.

A concern is that Tehran is making vague promises to carry it over the hurdle of the IAEA board meeting. On the other hand, the US, preoccupied with Ukraine, appears not to be in a mood to censure Iran over its nuclear programme or to try to restore the stalled nuclear deal.

At his press conference, Grossi dismissed public statements by Iranian officials that they would not give him access to key Iranian nuclear scientists, implying that behind the scenes they are sending him different messages.

Part 4: Ballistic Missiles

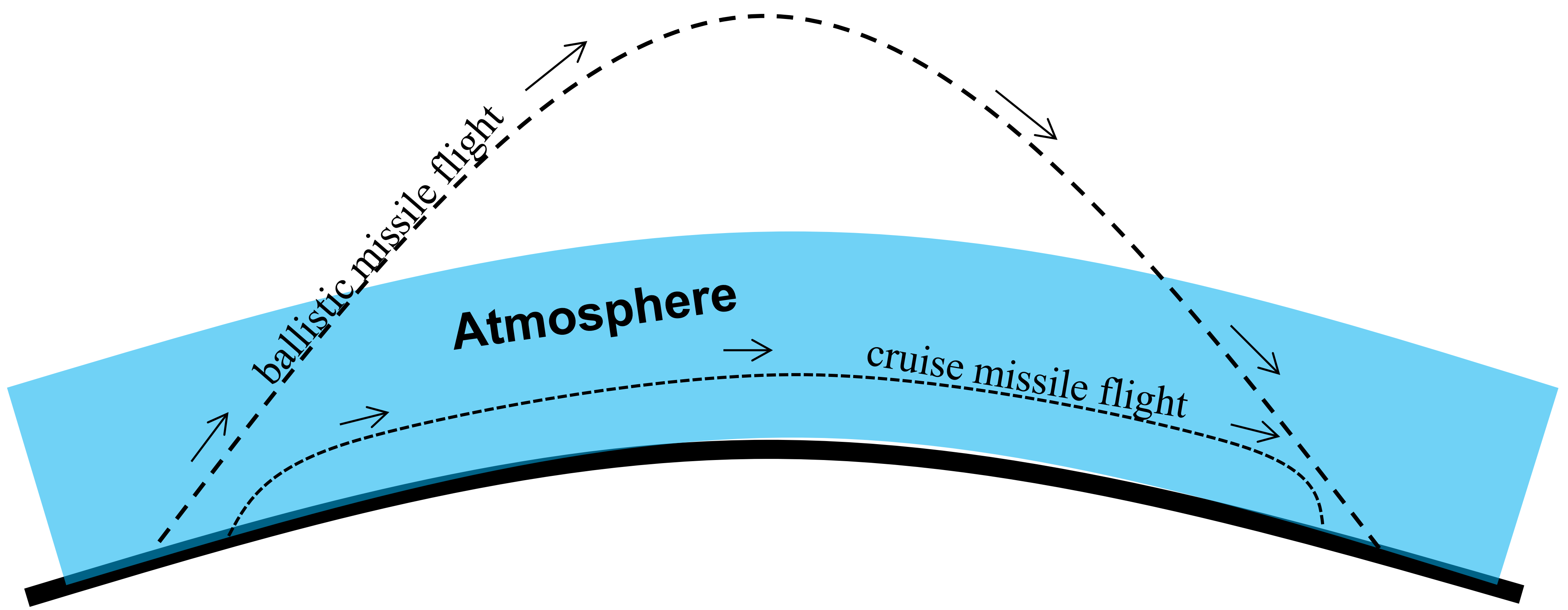
Air Breathing Delivery Systems (Bombers & Cruise Missiles) vs Ballistic Missiles

Air breathing systems:

- o carry the fuel on board but take the oxidizer from the atmospheres ➔ operate endo-atmospheric

Ballistic missiles:

- o carry fuel and oxidizer ➔ can operate exo-atmospheric



Attributes of Ballistic Missiles

Basing modes —

- Fixed (e.g., blast-hardened silos in the ground)
- Mobile (e.g., on railroad cars)

Propellants —

- Liquid (fuel and oxidizer are separate)
- Solid (fuel and oxidizer are mixed)

Payloads —

- Single warhead + penetration aids (“penaids”)
- Multiple warheads + penetration aids

Categories of Ballistic Missiles Based on Their Ranges (Important)

Short-range ballistic missiles (SRBMs) —

- Ranges under 1,000 km

Medium-range ballistic missiles (MRBMs) —

- Ranges between 1,000 km and 3,000 km

Intermediate-range ballistic missiles (IRBMs) —

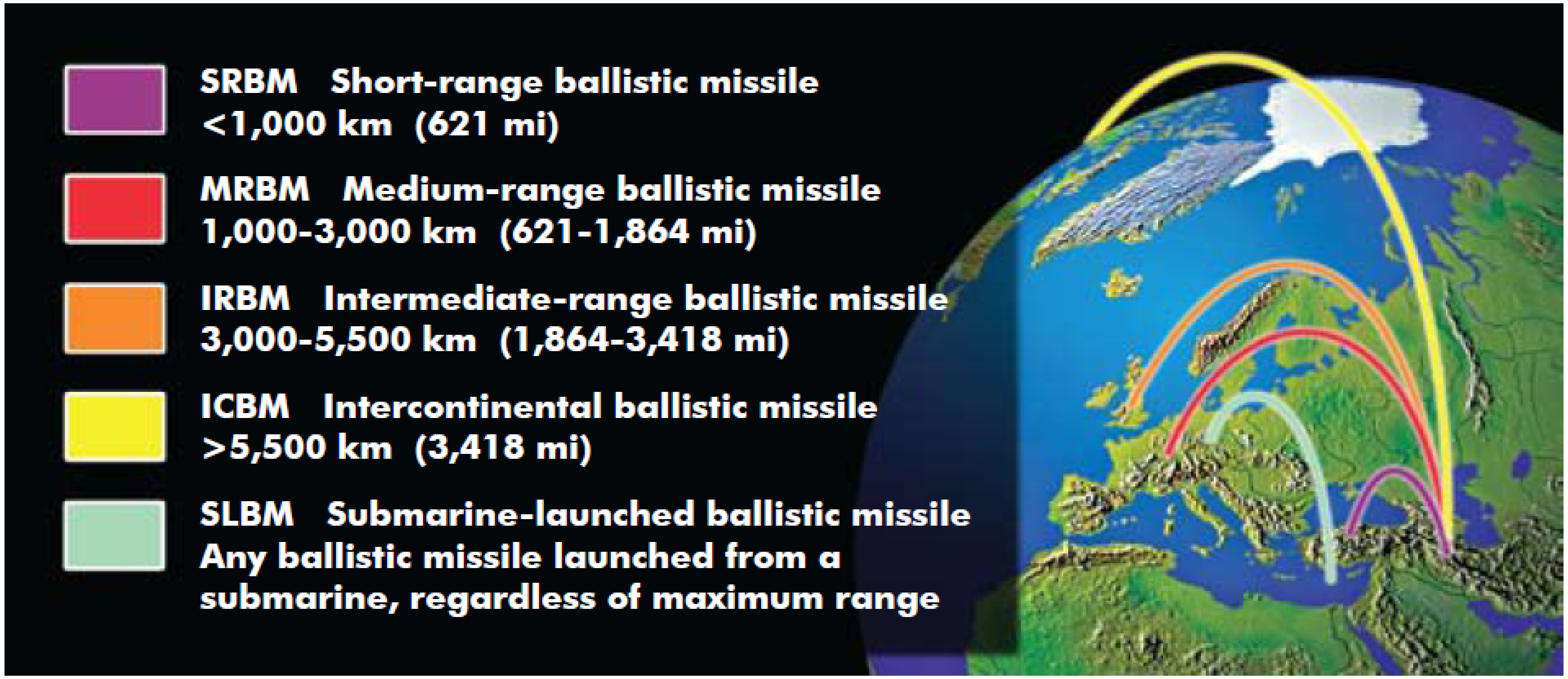
- Ranges between 3,000 km and 5,500 km

Intercontinental-range ballistic missiles (ICBMs, SLBMs) —

- Limited-range ICBMs (LRICBMs): 5,500 to 8,000 km
- Full-range ICBMs (FRICBMs): > 8,000 km
- Ranges of US and Russian ICBMs are ~ 12,000 km

These categories are not fluid, because they are based on the performance characteristics of the missile.

Categories of Ballistic Missiles Based on Their Ranges (Important)



Source: national air and space intelligence center

"Ballistic and Cruise Missile Threat", 2009

Intercontinental-range ballistic missiles (ICBMs, SLBMs) —

- Limited-range ICBMs (LRICBMs): 5,500 to 8,000 km
- Full-range ICBMs (FRICBMs): > 8,000 km
- Ranges of US and Russian ICBMs are ~ 12,000 km

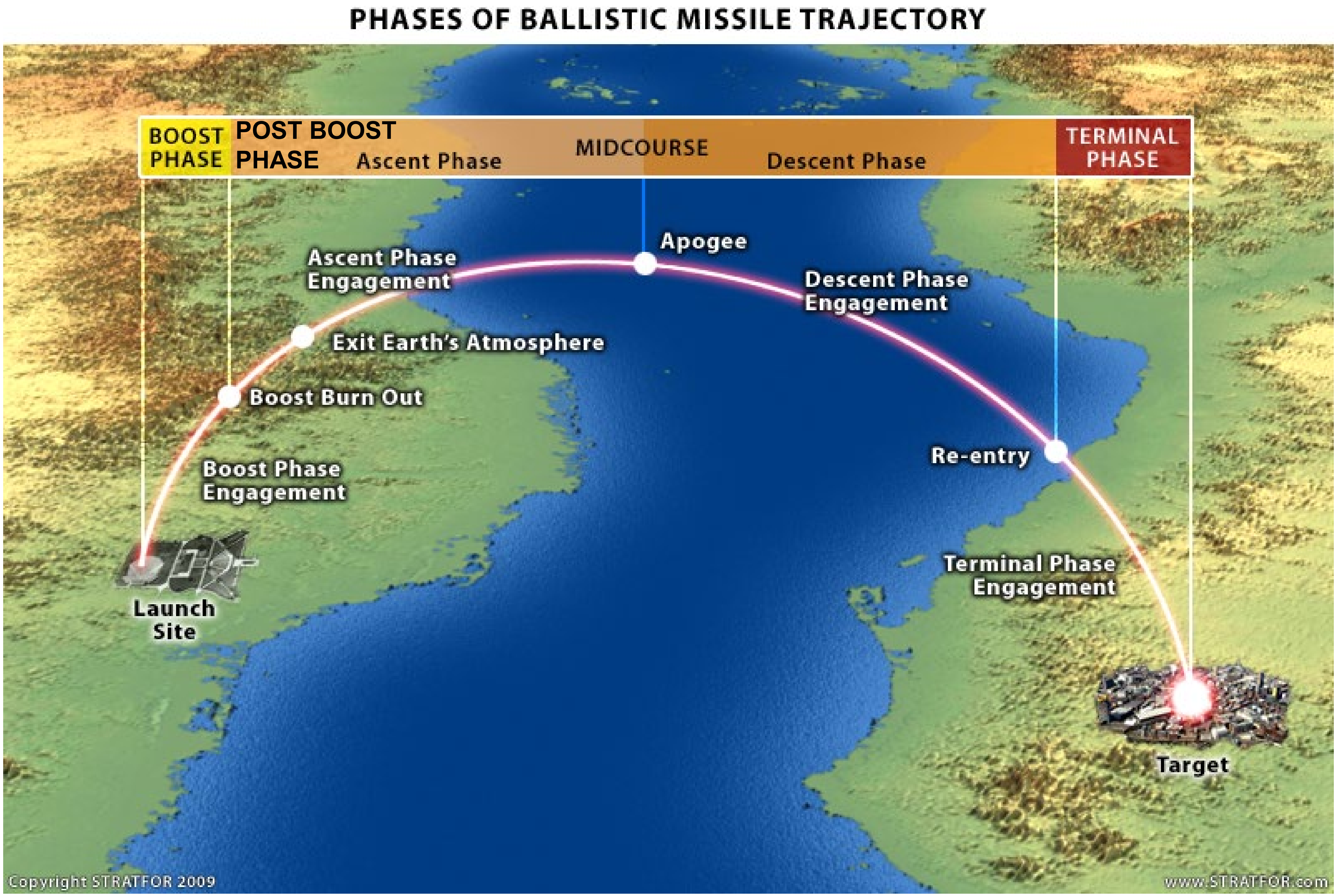
These categories are not fluid, because they are based on the performance characteristics of the missile.

Phases of Flight of Intercontinental-Range Ballistic Missiles (Important)

Basic phases of flight of a (MIRVed) intercontinental ballistic missile (ICBMs and SLBMs) —

- Boost phase: rocket motors burning
- Post-boost phase (release of payload from bus)
- Midcourse phase: ballistic motion in space
- Terminal phase: re-entrance into atmosphere and passage through atmosphere

Phases of Flight of Intercontinental-Range Ballistic Missiles (Important)



Categories of Ballistic Missiles Based on Their Purposes

Tactical ballistic missiles (TBMs) —

- For use on the battlefield (e.g., on a particular front)
- Usually have shorter ranges (SRBMs)

Theater ballistic missiles (TBMs) —

- For use in an entire theater of war (e.g., the Middle East)
- Usually have longer ranges than tactical missiles

Strategic ballistic missiles (an example of SNDVs – Strategic Nuclear Weapons Delivery Vehicle) —

- For attacking the homeland of the adversary
- May have longer, possibly intercontinental ranges

These categories are fluid, because they are based on the intent of the user at the time the missile is fired.

Missile Guidance Technologies

Inertial —

- Uses gyroscopes and accelerometers
- No contact with outside world

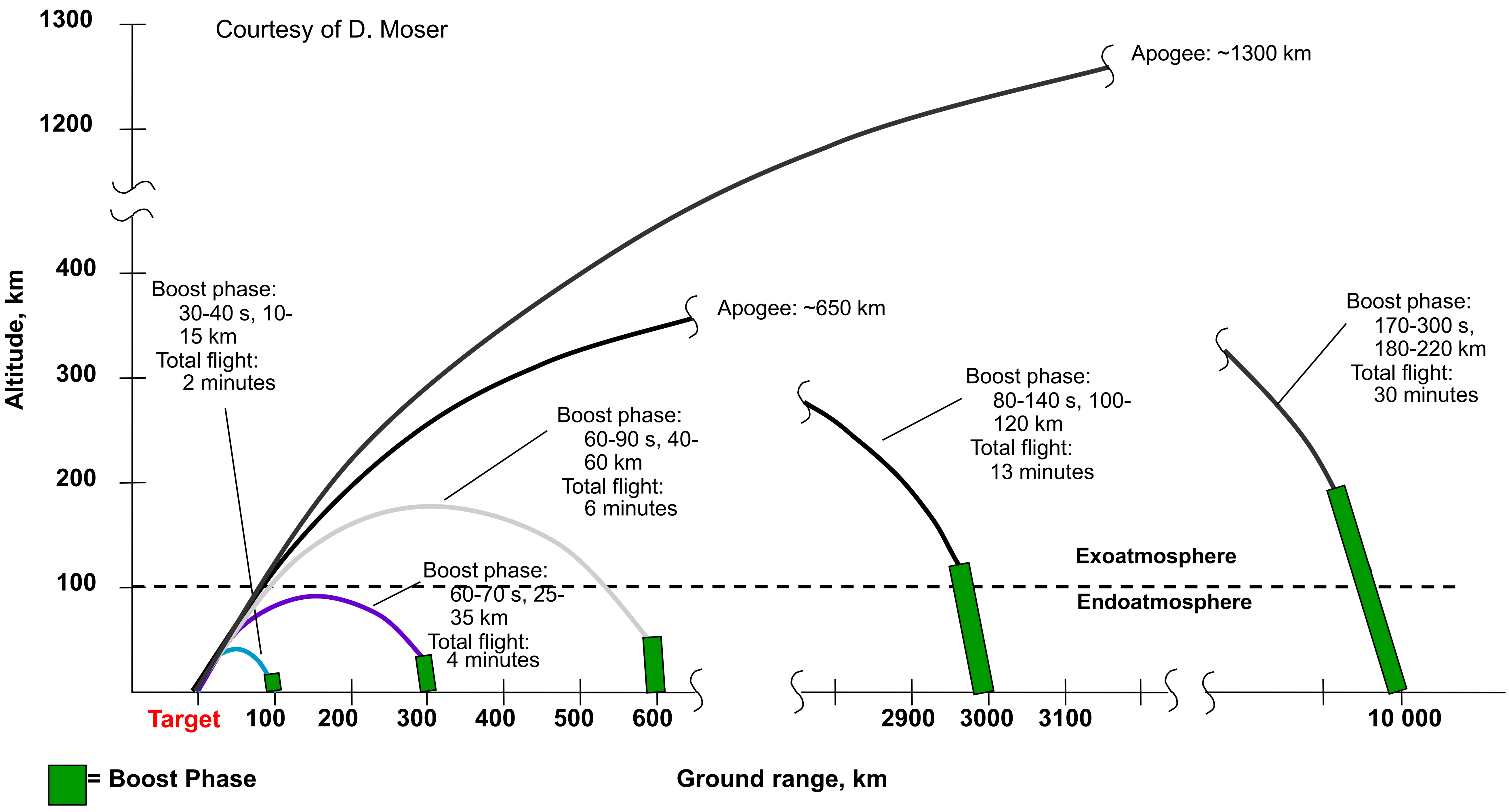
Stellar —

- Star trackers update inertial guidance system

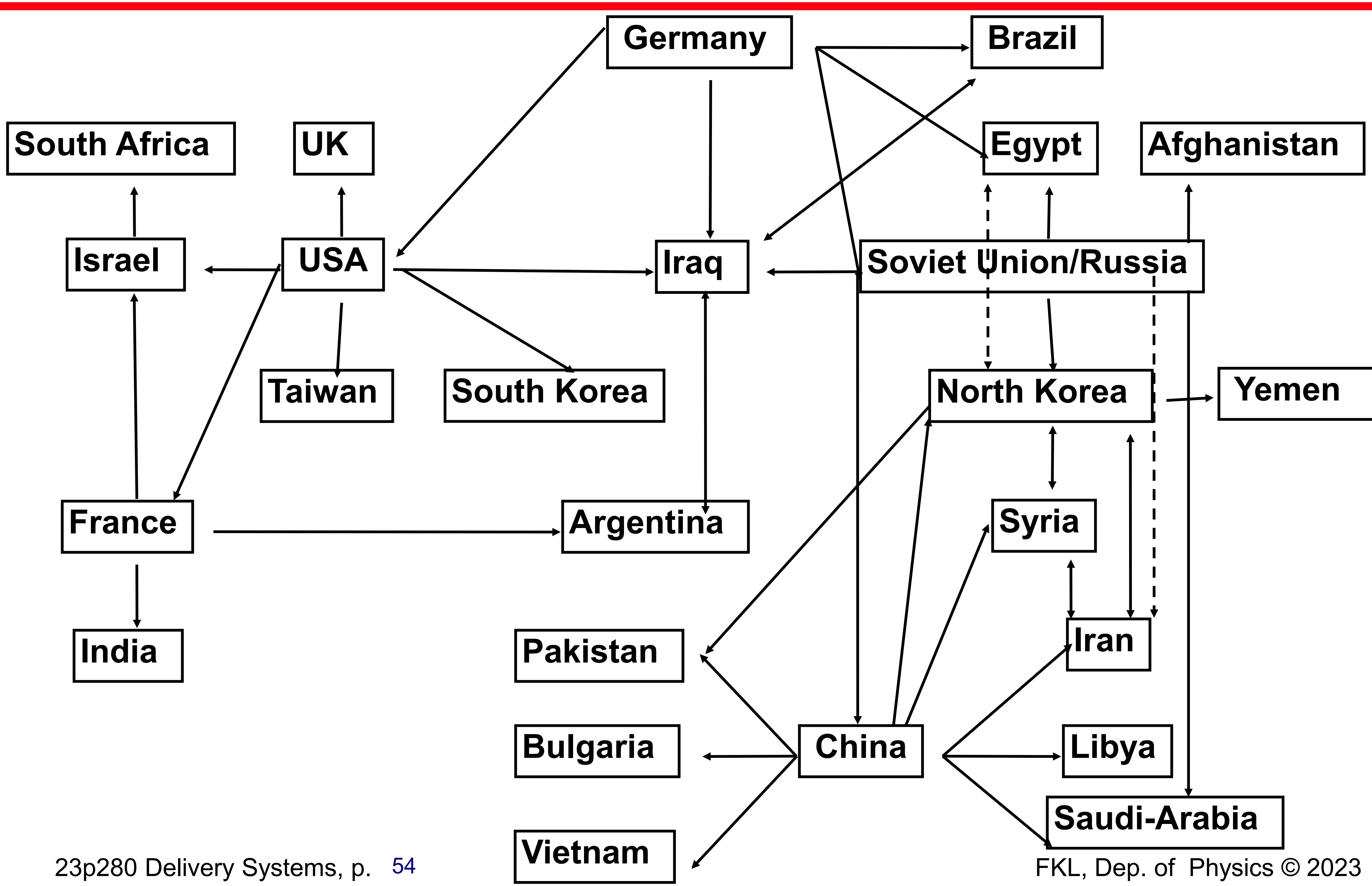
Satellite —

- Uses accurate (atomic) clocks on satellites
- Uses coded radio transmissions
- Uses sophisticated receivers
- Can determine both position and velocity very accurately using signals from 3 to 4 satellites

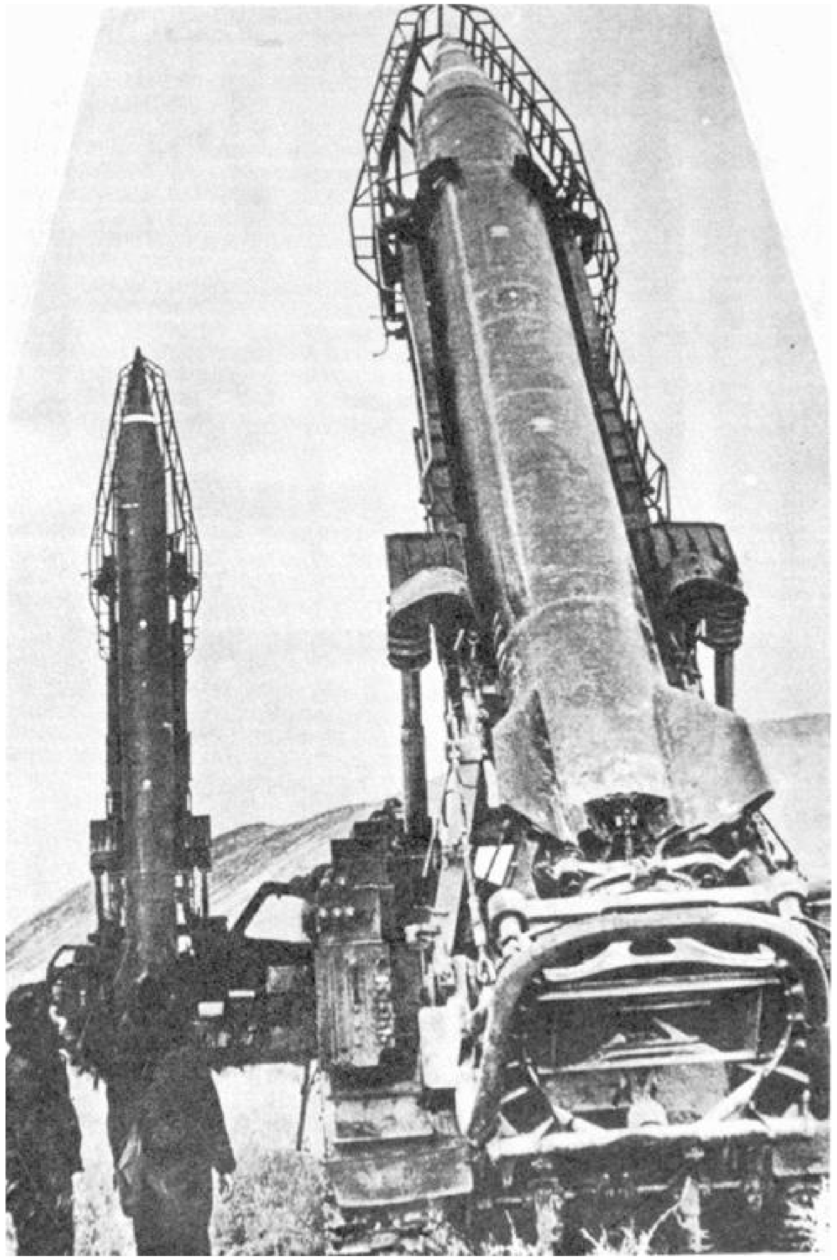
Trajectories and Phases of Flight of Missiles With Various Ranges



Proliferation of Ballistic Missile Technologies



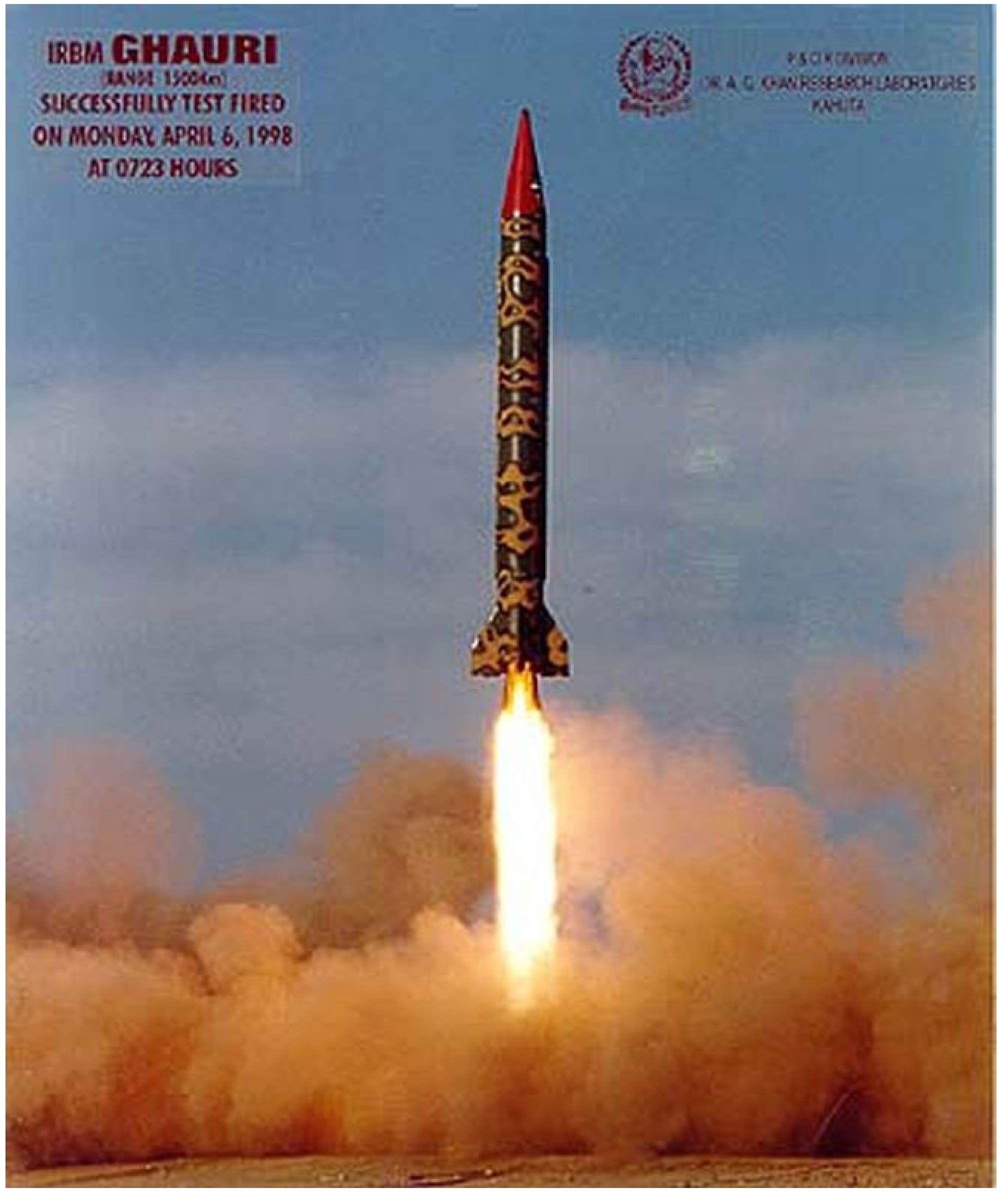
Soviet Scud Missiles and Derivatives - 1



Soviet Scud-B Missile
(based on the German V2)
Range: 300 km

Iraqi Al-Hussein SRBM
Range: 600–650 km

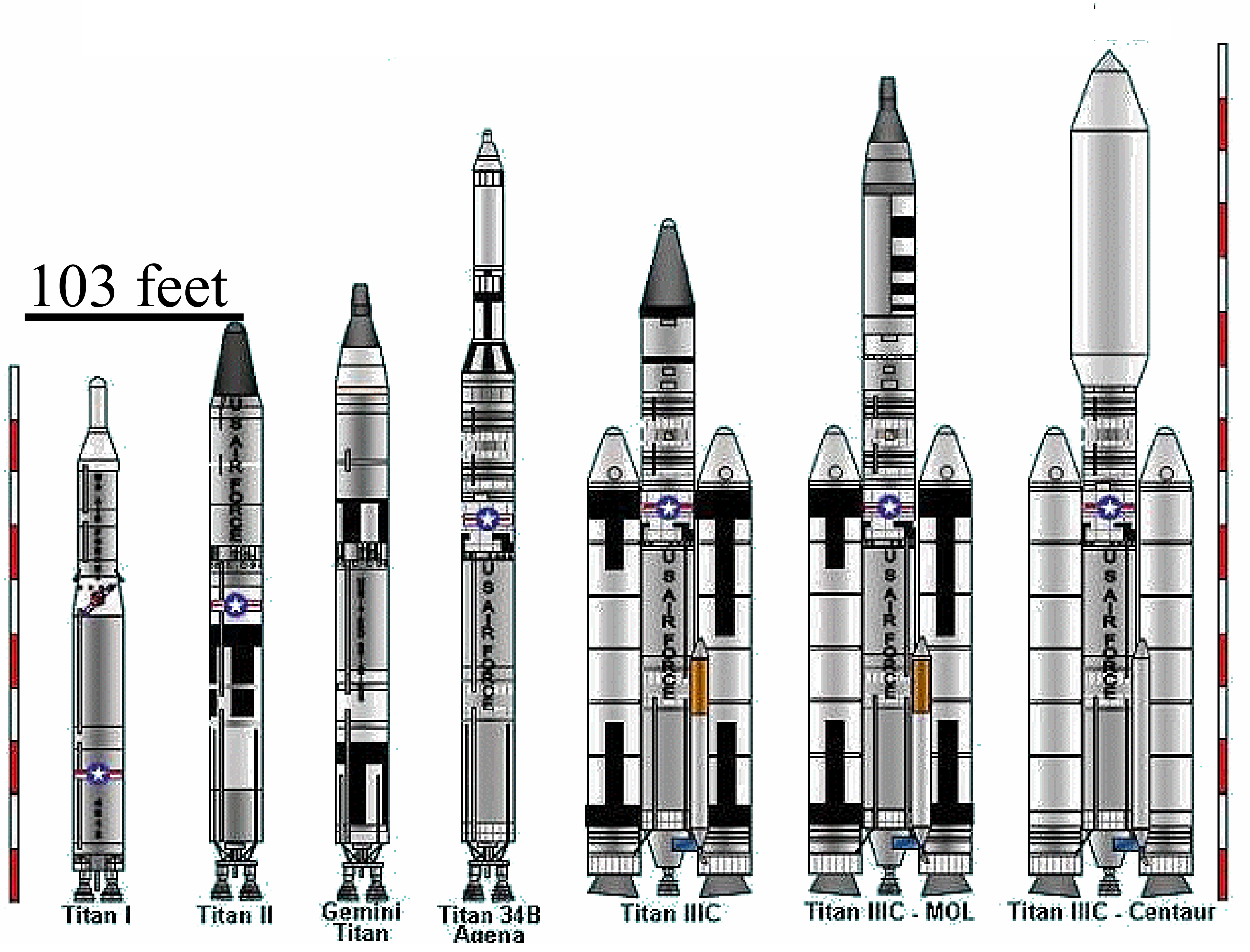
Scud Missiles and Derivatives – 2



Pakistan's Ghauri MRBM and transporter (range 1,300 km).
It is almost identical to North Korea's No Dong MRBM, which is based on Scud technology that North Korea got from Egypt in the 1970s.

Titan Family of Missiles and Launch Vehicles

1959 – 2005 ICMB & civilian uses



TIME Magazine, **Monday September 29th 1980**

Light on the Road to Damascus

Titan terror explodes in the Arkansas hills

Shortly after sunset one day last week, a maintenance worker on the third level of a silo housing a 103-ft. Titan II Intercontinental ballistic missile near Damascus, in the Arkansas hills north of Little Rock, dropped the socket of a wrench. The 3-lb. tool plummeted 70 ft. and punctured a fuel tank. As flammable vapors escaped, officials urged the 1,400 people living in a five-mile radius of the silo to flee. The instructions: "Don't take time to close your doors—just get out.“ And with good reason. At 3:01 a.m., as technicians gave up trying to plug the leak and began climbing from the silo, the mixture of fuel and oxygen exploded. Orange flames and smoke spewed out, lighting up the sky over Damascus. The blast blew off a 750-ton concrete cover. One worker was killed; 21 others were hurt.

Today: LGM-30G Minuteman III ➔ 3 stage solid rocket fuel
Range: 11,000km +
Speed : 24,100 km/h or 6.7km/s (terminal phase)

Re-Entry Vehicles (RVs)

Basic types —

- MRV = multiple RV
  - —Final stage carries more than 1 RV
  - —Final stage has no propulsion
  - —RVs are *not* independently targetable
- MIRV = multiple, independently targetable RV
  - —Final stage carries more than 1 RV
  - —Final stage has guidance package and propulsion
  - —RVs are independently targetable
- MARV = maneuverable RV
  - —RV has a guidance package
  - —RV maneuvers during the terminal phase, using, e.g., thrusters or aerodynamic forces

MK21 re-entry vehicles on Peacekeeper MIRV bus

MIRV Technology

MX Peacekeeper MIRV

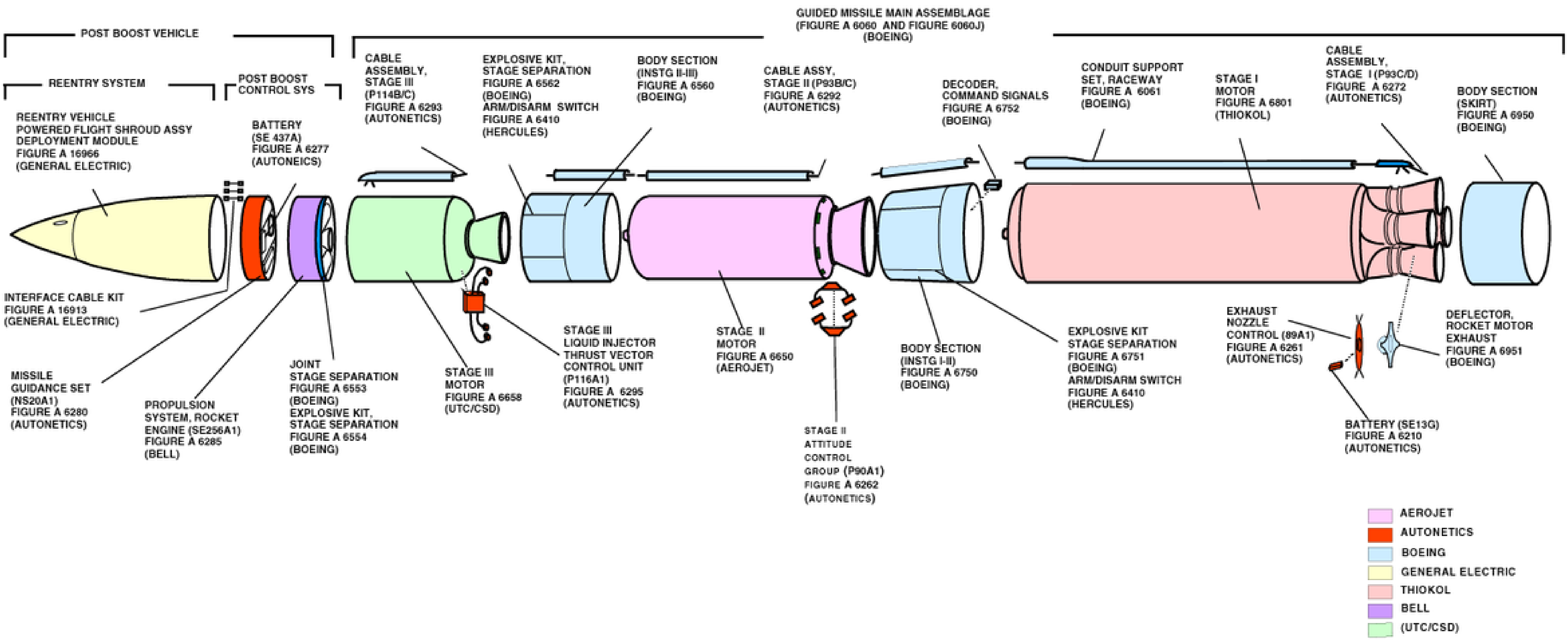
Soviet ICBM MIRV

MIRV Technology

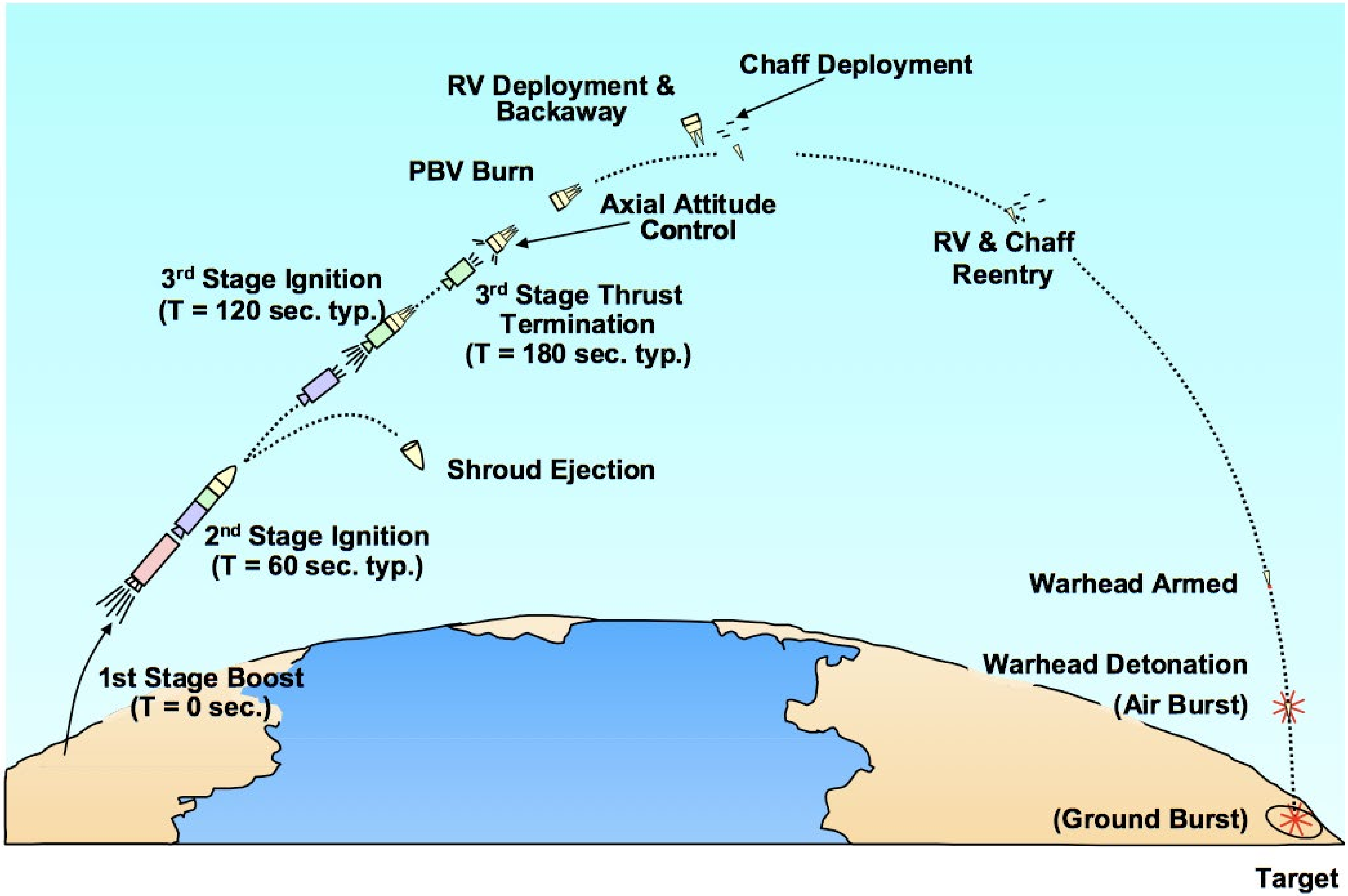
MX Peacekeeper missile tested at Kwajalein Atoll

Source:www.smdc.army.mil/kwaj/Media/Photo/missions.htm

Minuteman ICBM (Schematic)



Flight of a Minuteman ICBM (Schematic)



Flight of MIRV’d ICBMs

Four phases of the flight of an intercontinental-range missile armed with MIRVs (Multiple Independently Targetable Reentry Vehicles)—

- Boost phase (lasts about 1–5 min)
  - — Rocket motors are burning
  - — Missile rises through the atmosphere and enters near-Earth space
  - — Stages drop away as they burn out
- Post-boost phase (lasts 5–10 min)
  - — Bus separates from the final stage
  - — Bus maneuvers and releases RVs
- Midcourse phase (lasts about 20 min)
  - — RVs fall ballistically around the Earth, in space
- Terminal phase (lasts about 20–60 sec)
  - — RVs re-enter the Earth’s atmosphere and encounter aerodynamic forces
  - — RVs fall toward targets, until detonation or impact

Examples of US and Russian ICBMs

Recent US ICBMs —

- MX Solid-propellant, range ~ 12,000 km,
  10 warheads (Peacekeeper, retired 2005)
- MMIII Solid-propellant, range ~ 12,000 km,
  Capability for 3 warheads (Minuteman)
  Presently deployed with 1 warhead

Recent Russian ICBMs —

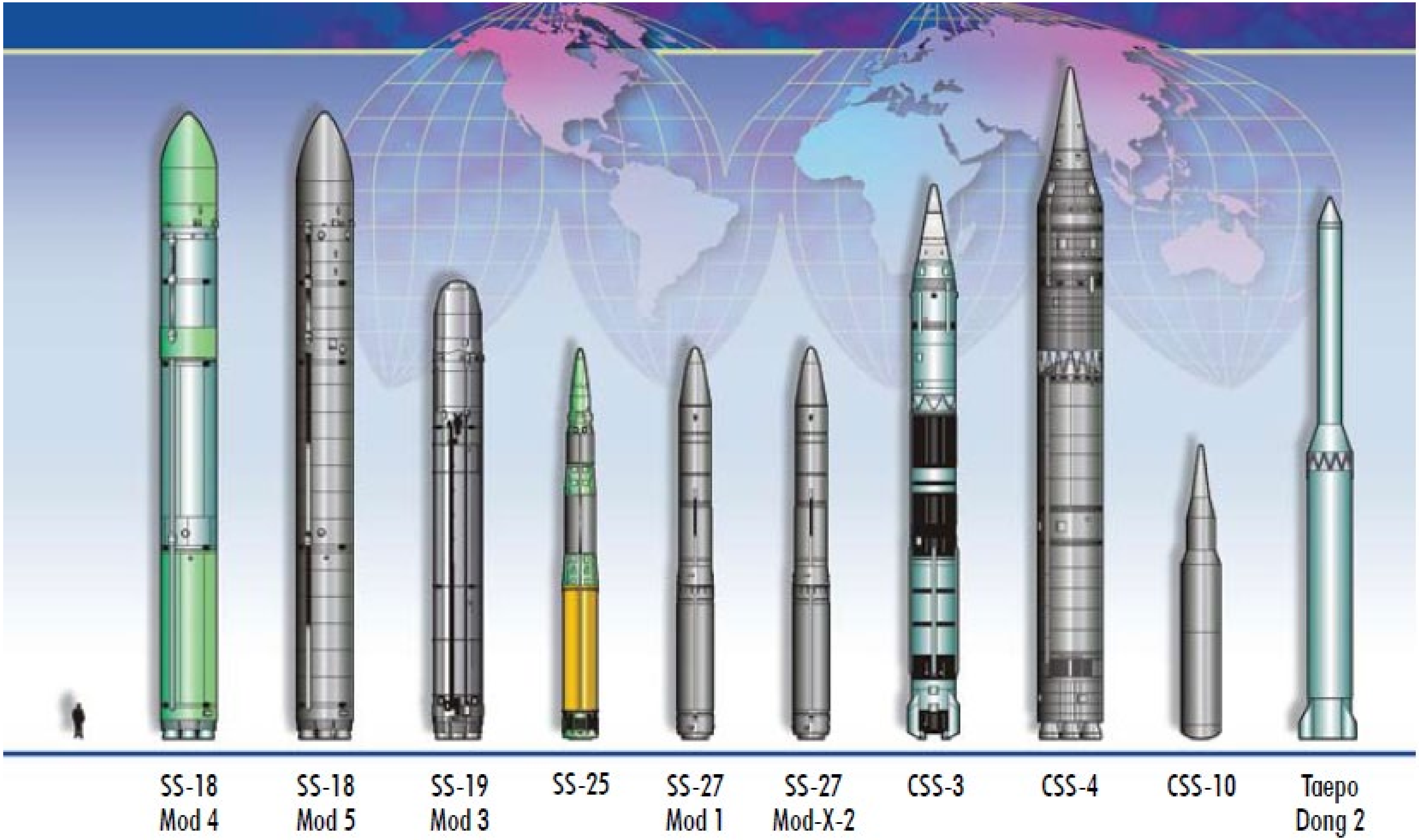
- SS-24 Solid-propellant, range > 9,000 km
- SS-25 Solid-propellant, range > 9,000 km
- SS-27 Solid-propellant, range > 9,000 km

US ICBMs – 2

Launch of a Minuteman ➔ video!

Launch of an MX

Russian, Chinese and North Korean ICBMs – 1



Source: national air and space intelligence center
"Ballistic and Cruise Missile Threat", 2009

Russian, Chinese and North Korean ICBMs – 2

Missile	Number of Stages	Warheads per Missile	Propellant	Deployment Mode	Maximum Range* (miles)	Number of Launchers
Russia						
SS-18 Mod 4	2 + PBV	10	Liquid	Silo	5,500+	104
SS-18 Mod 5	2 + PBV	10	Liquid	Silo	6,000+	(total for Mods 4 & 5)
SS-19 Mod 3	2 + PBV	6	Liquid	Silo	5,500+	122
SS-25	3 + PBV	1	Solid	Road-mobile	7,000	201
SS-27 Mod 1	3 + PBV	1	Solid	Silo & road-mobile	7,000	54
SS-27 Mod-X-2	3 + PBV	Multiple	Solid	Silo & road-mobile	7,000	Not yet deployed
China						
CSS-3	2	1	Liquid	Silo & transportable	3,400+	10 to 15
CSS-4 Mod 2	2	1	Liquid	Silo	8,000+	About 20
CSS-10 Mod 1	3	1	Solid	Road-mobile	4,500+	Fewer than 15
CSS-10 Mod 2	3	1	Solid	Road-mobile	7,000+	Fewer than 15
North Korea						
Taepo Dong 2	2	1	Liquid	Undetermined	3,400+	Not yet deployed

Source: national air and space intelligence center
"Ballistic and Cruise Missile Threat", **2009**

Plan for This Session

Please turn in RE3v2 into 280 homework box in Loomis

News

- ➔ midterm will be Thursday March 23rd
- ➔ midterm will cover modules 1 to 5 + news
- ➔ old tests are available on course web-page
- ➔ review session during Wednesday office hours on March 22nd

Module 5: Nuclear Weapon Delivery Systems

European Security & Defence

European Security & Defence

UK's Future SSBN is On Time and On Budget, Says MoD

The UK Ministry of Defence (MoD) published an update of its report to parliament on the status of programmes related to the United Kingdom's future nuclear deterrent on 8 March 2023.

The main sections of the report cover production of the Royal Navy's future fleet of four Dreadnought-class nuclear-powered ballistic missile submarines (SSBNs), upgrades to the submarine-launched ballistic missiles (SLBMs) that will arm them and the nuclear warheads these missiles will carry, and progress with infrastructure related to the delivery of the UK's future sea-based nuclear deterrent.

Post-introduction, the top line of the report states that the Dreadnaught SSBN programme "remains within its overall budget and on track for the first of class, HMS *Dreadnaught*, to enter service in the early 2030s".

BAE Systems is building the four Dreadnaught-class boats to replace the Royal Navy's current fleet of four Vanguard-class SSBNs, which were commissioned from 1993 and currently provide the UK's continuous at-sea nuclear deterrent.

Construction of the first two SSBNs, *Dreadnaught* and *Valiant*, is currently underway, while BAE Systems announced on 9 February 2023 that work on construction of the third boat, to be called *Warspite*, had now begun.

Once the Dreadnaught class enters service with the Royal Navy it is due to operate for at least 30 years.

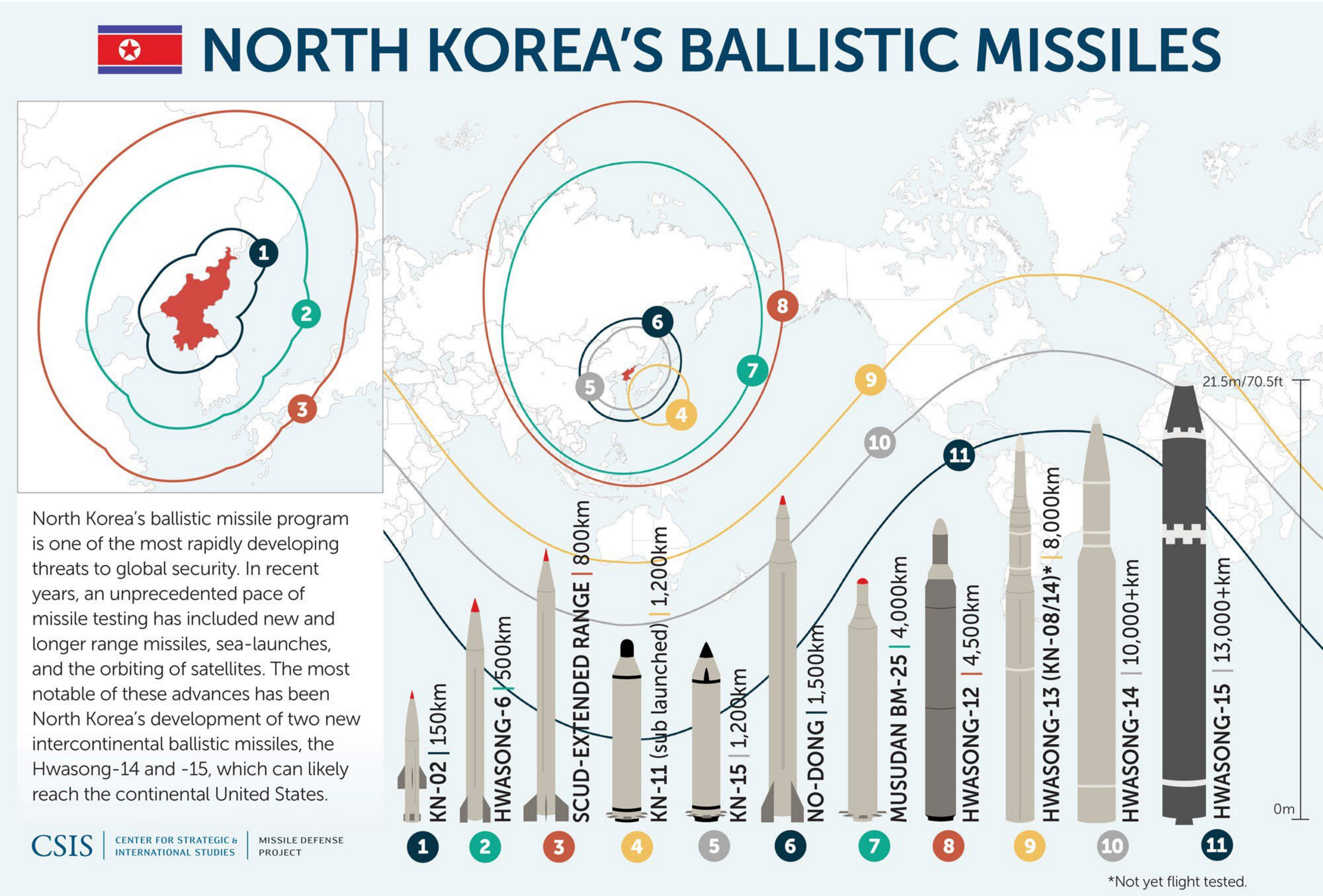
European Security & Defence

UK's Future SSBN is On Time and On Budget, Says MoD

In terms of costs the MoD report noted that the UK's 2015 Strategic Defence and Security Review estimated that the Dreadnaught programme is likely to cost a total of GBP 31 billion (including inflation) over its lifetime and set a contingency of GBP 10 Bn. "The programme remains within this overall budget," the report stated, "and, as of 31 March 2022, GBP 12.5 Bn had been spent on the concept, assessment, and early delivery phases of the Dreadnought programme.

Regarding the Dreadnaught class's armament, the UK is upgrading and life-extending both the current warheads and the SLBMs that will carry them while working on a new warhead design. In this area the MoD report said that the programme to replace the UK's sovereign nuclear warhead "has now entered its concept phase", while the "transition of the current warhead from Mark 4 to Mark 4A continues, addressing obsolescence to ensure that the UK has a safe, secure, and available stockpile until the UK Replacement Warhead is available in the 2030s."

The report further explained that the UK's in-service and future replacement warheads will "remain compatible with the Trident II D5 missile that is deployed on the Vanguard class and will be deployed on the new Dreadnought- class submarines", adding that the UK "is working with US partners on work to extend the life and replenish the Trident II D5 missiles to meet the future programme requirements of both nations".


NORTH KOREA'S BALLISTIC MISSILES
North Korea's ballistic missile program is one of the most rapidly developing threats to global security. In recent years, an unprecedented pace of missile testing has included new and longer range missiles, sea-launches, and the orbiting of satellites. The most notable of these advances has been North Korea's development of two new intercontinental ballistic missiles, the Hwasong-14 and -15, which can likely reach the continental United States.
KN-02 | 150km
HWASONG-6 | 500km
SCUD-EXTENDED RANGE | 800km
KN-11 (sub launched) | 1,200km
KN-15 | 1,200km
NO-DONG | 1,500km
MUSUDAN BM-25 | 4,000km
HWASONG-12 | 4,500km
HWASONG-13 (KN-08/14)* | 8,000km
HWASONG-14 | 10,000+km
HWASONG-15 | 13,000+km
21.5m/70.5ft
0m
1 2 3 4 5 6 7 8 9 10 11
*Not yet flight tested.
CSIS CENTER FOR STRATEGIC & INTERNATIONAL STUDIES
MISSILE DEFENSE PROJECT

Russian, Chinese and North Korean ICBMs – 4

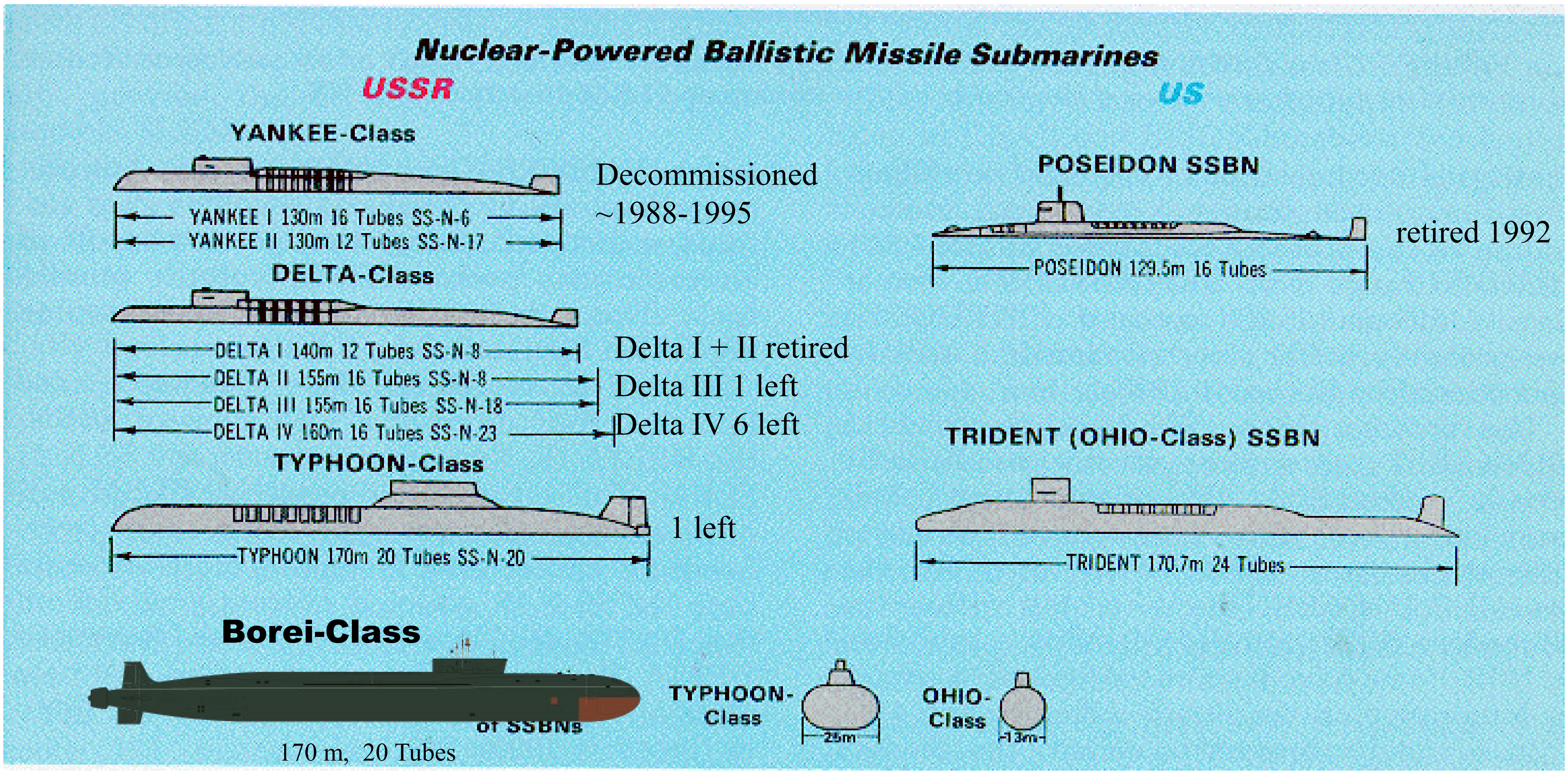
The Russian Dnepr space launch vehicle is based on the SS-18 ICBM.

Chinese CSS-10 Road-Mobile Launcher

ICBM

Russian SS-27 Road-Mobile Launcher

US and Russian SSBNs



US Trident SSBN (14 SSBNs, 4 SSGNs)

Trident Missile Tubes
With Covers Open

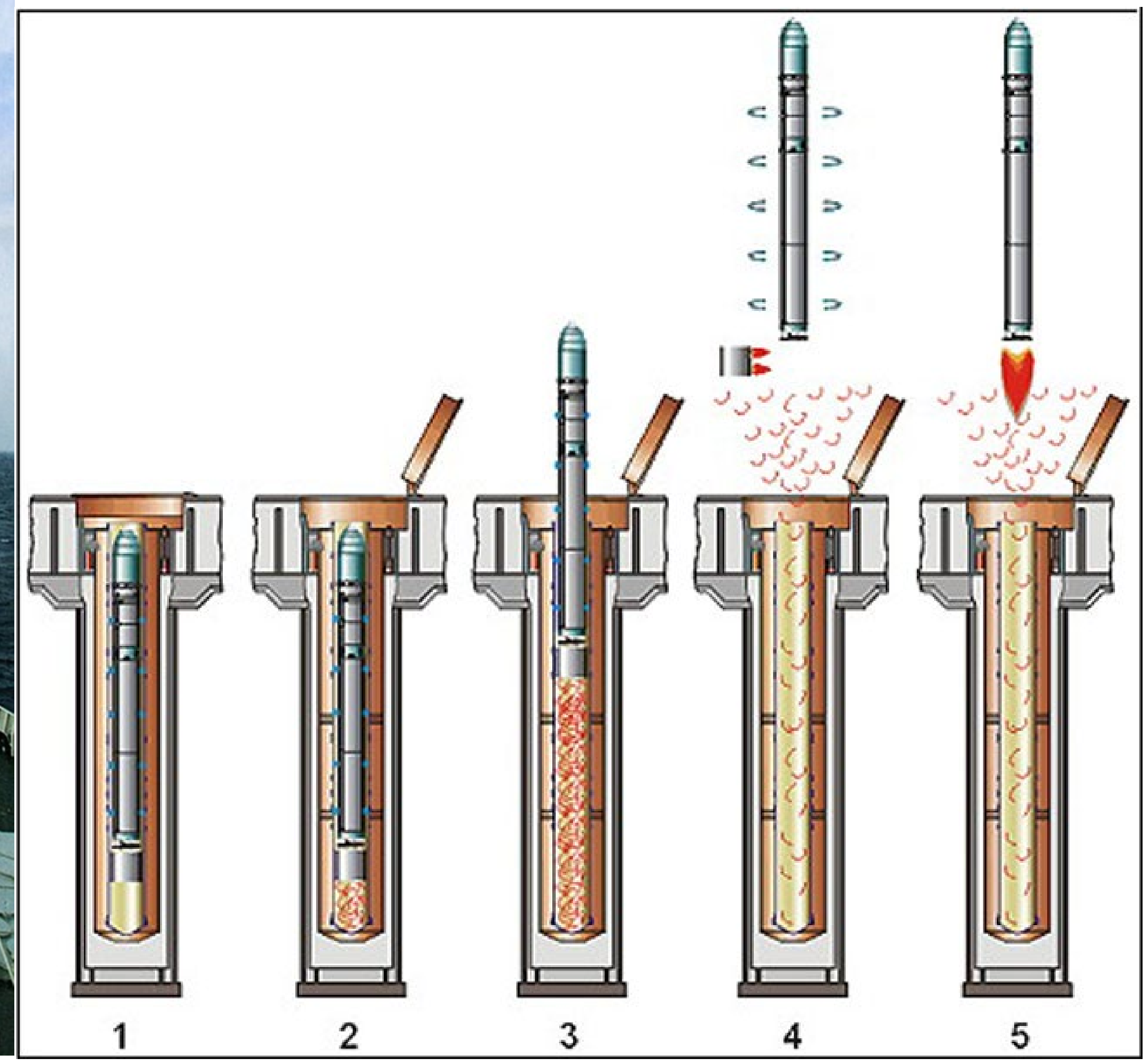
Trident Submarine Underway

24 Trident C4 SLBMs
8 MIRVs with 100kt W76
➔ up to192 targets
SLBM range 7400 km

speed	: 20 knots
SSBN range	: unlimited
deployment	: 70-90 days, two rotating crews
Displacement	: 16500 tons
Length	: 170 m
width	: 13 m

Cold Launch Mode

Missile is ejected with high pressure steam before rocket engines are started: “Cold Launch”



US Trident SSBN

Launch video

Submarine-Based Missiles

US SLBMs —

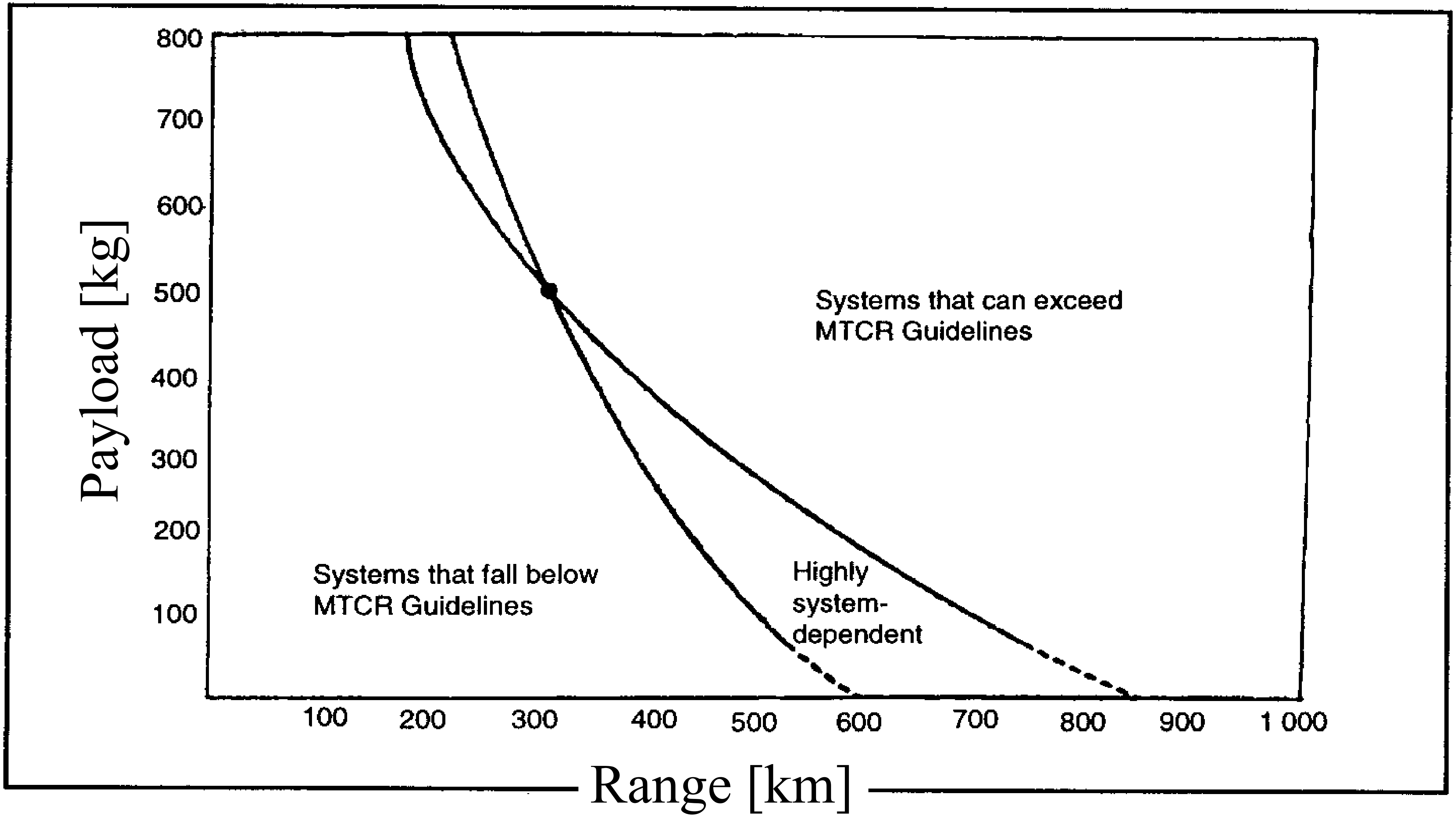
- Trident C4 missiles carried 8 MIRVs each (solid propellant, range 7400 km)
- Trident D5 missiles carry 8 MIRVs each (solid propellant, range 7400 km)

Russian SLBMs —

- SS-N-8 missiles carried 1 warhead each (range 9100 km)
- SS-N-18 missiles carried 3 warheads each (liquid propellant, range 6500 km)
- SS-N-20 missiles carried 10 warheads each (solid propellant, range 8300 km)
- SS-N-23 missiles carried 4 warheads each (liquid propellant, range 8300 km)

Part 5: Technical and Operational Aspects

MTCR: Range-Payload Limits

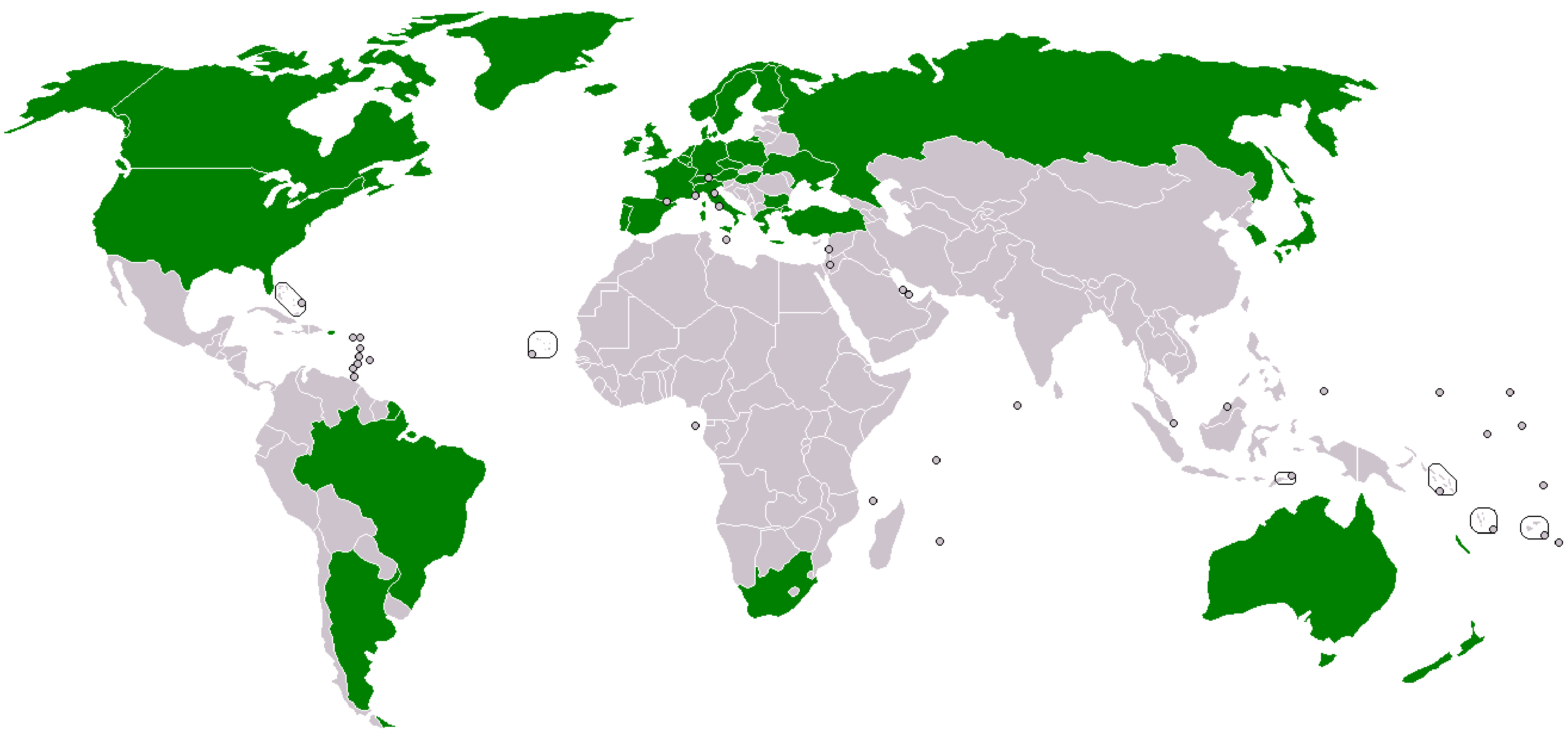


MTCR is the 1987 Missile Technology Control Regime to restrain missile exports

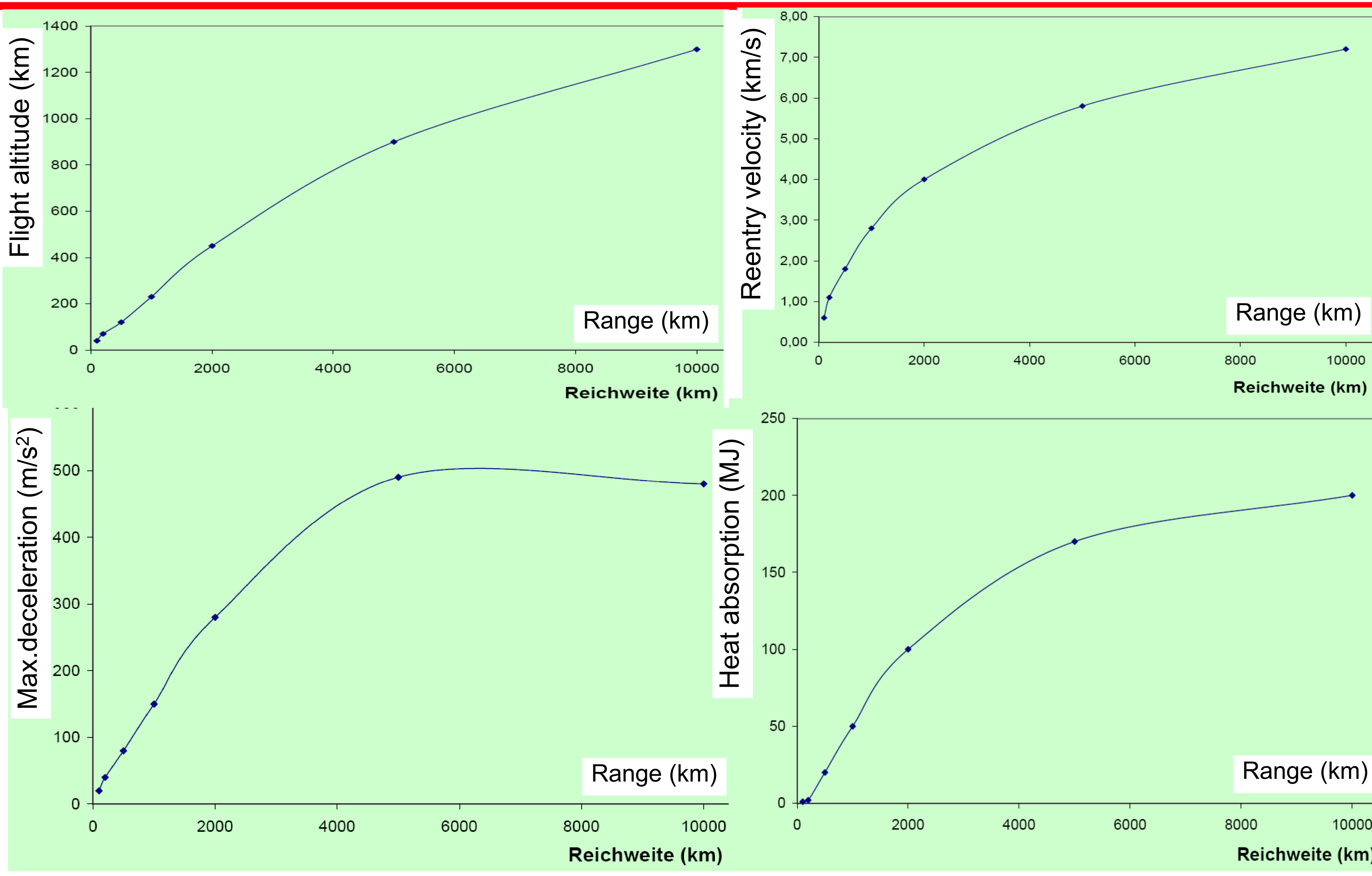
A. Karp, Ballistic Missile Proliferation, sipri, 1996, p. 157

1987 Missile Technology Control Regime

34 member countries (the leading missile producing countries have agreed to restrict missile exports).
China and Israel are not members but have agreed unilaterally to adhere to the provisions of the agreement.



The Performance Required for Missile Warheads Increases Greatly with Increasing Missile Range



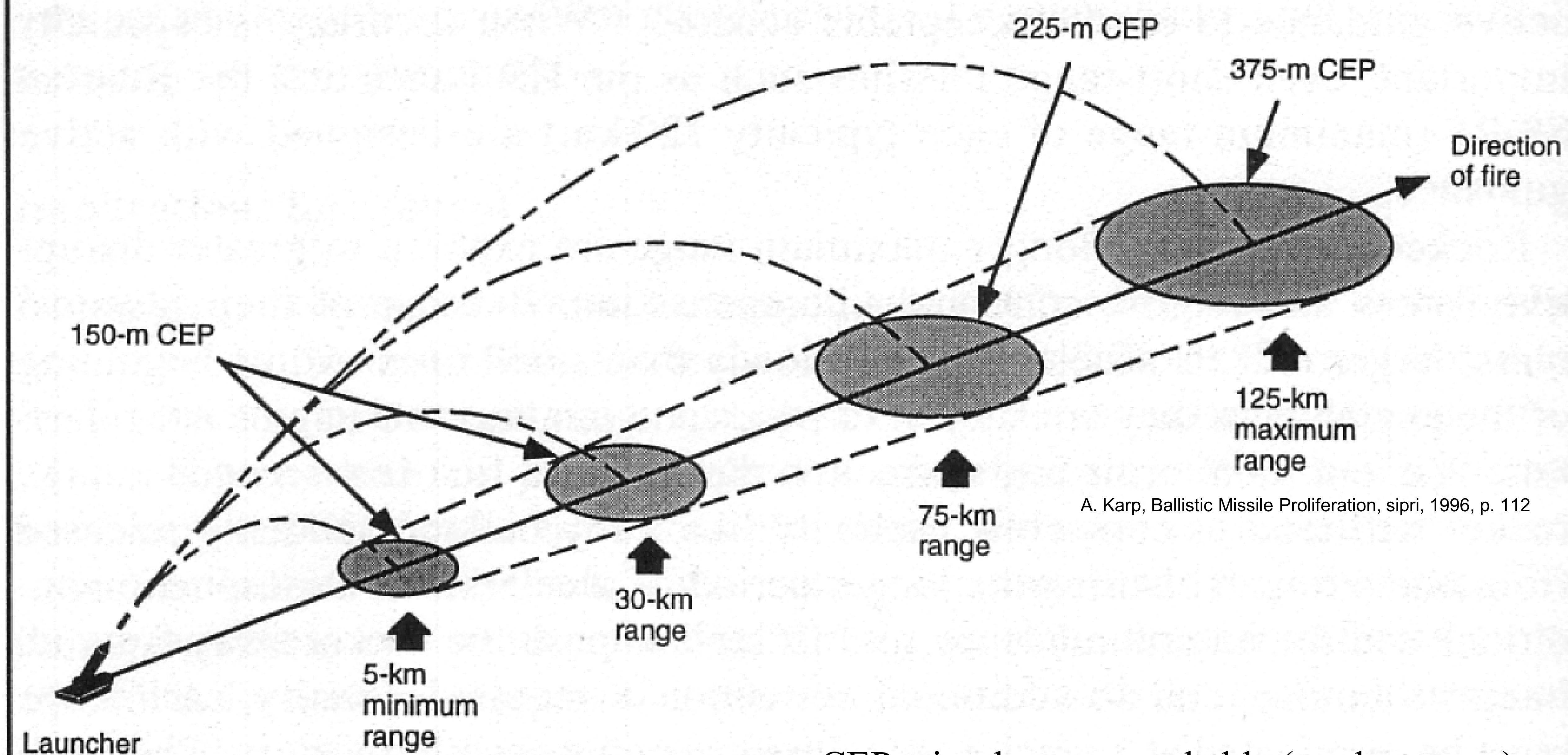
How Does this Translate into Challenges During Re-Entry into the Atmosphere?

Large frictional forces on re-entry lead to

➔deceleration up to 500 m/s^2 = 51 g
~ car with 70mph into concrete wall
g-forces can be lethal if > 25 g

➔200 MJ of energy is enough to heat
W76 warheads to the melting temperature
of iron ~ 1540 C !

Missile Range–Accuracy Tradeoff



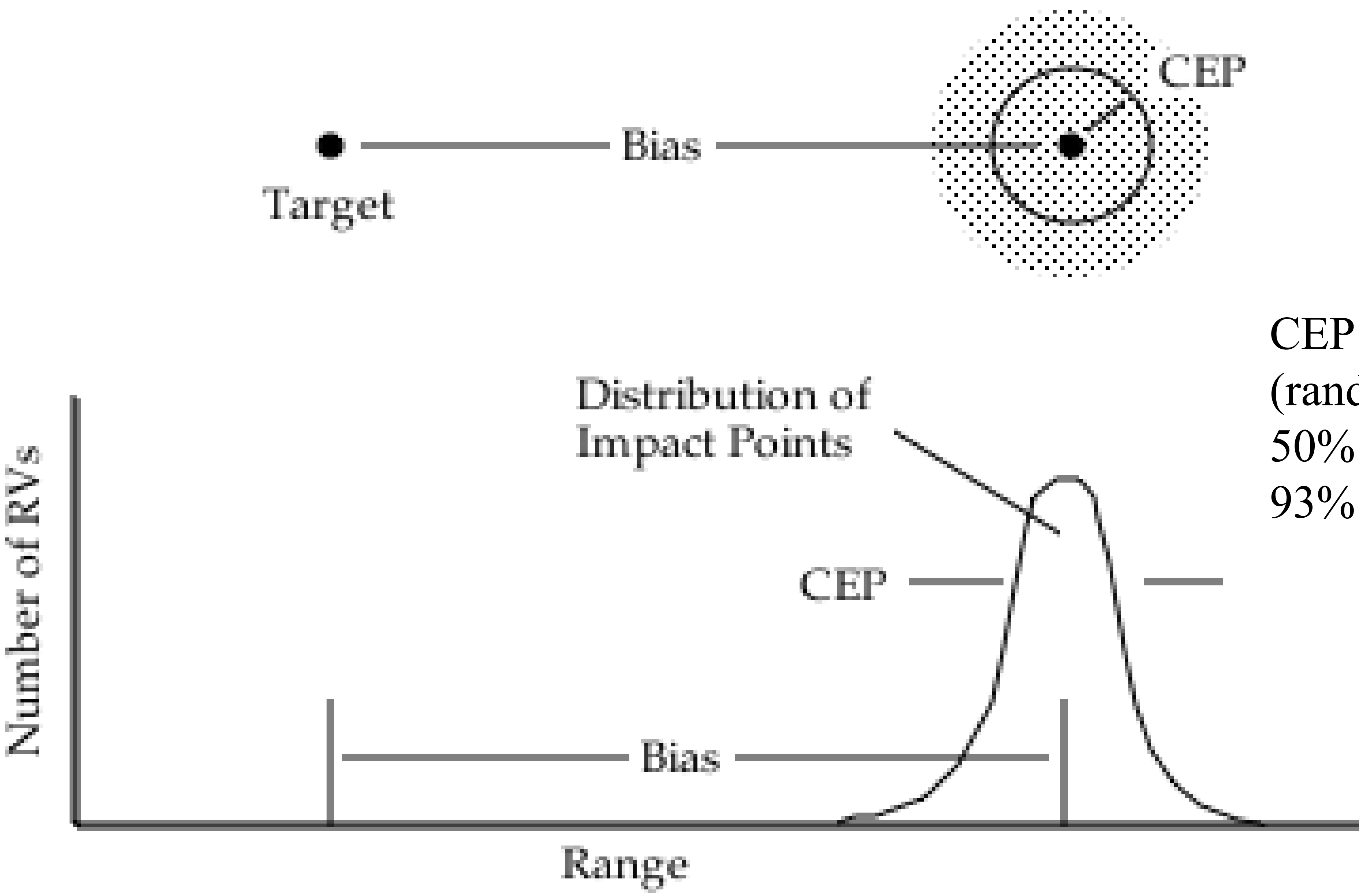
A. Karp, Ballistic Missile Proliferation, sipri, 1996, p. 112

Lance missile

CEP: circular error probable (random error)
50% of missiles land within CEP from target
93% within 2 x CEP from target

Ballistic Missile Accuracy

Distribution of RV impact points —



CEP: circular error probable
(random error)
50% of missiles land within CEP,
93% within 2 x CEP from target

Ballistic Missile Accuracy

The accuracy of a ballistic missile—like the value of *any* physical quantity—can only be specified *statistically*.

Important concepts:

- D = total miss distance
- CEP = "circular error probable" (random error)
- B = Bias (systematic error)

Relation —

$$D = (B^2 + CEP^2)^{1/2}$$

CEP is *not* a measure of the miss distance. The miss distance is *at least as large* as the CEP, but can be *much larger* if there is significant bias.

Ballistic Missile Accuracy

Published CEPs for some ICBMs and SLBMs		
	Missile	CEP
US	MMIII	220 m
	Trident II	100 m
Russia	SS-18	450 m
	SS-27	350 m
	SS-27 Sickle B	200 m

ICBM Accuracy & Vulnerability

Missile accuracy steadily improved during the Cold War as the result of technological innovation.

As ICBMs become more accurate, they become more vulnerable to attack by the adversary, increasing crisis instability.

Each ICBM and each SLBM was armed with more and more warheads during the Cold War.

As each missile was armed with more warheads, it became a greater threat to the nuclear forces of the adversary and a more attractive target for a pre-emptive or first strike, increasing crisis instability.

Silo-Based Missiles

Vulnerable to attack

- Silo locations are known very accurately
- MIRVed missiles make it possible to launch several warheads against an array of silos

Effect of silo hardness

- Hardening is expensive
- US assumes its silos can withstand 2,000 psi (5 psi will completely destroy a brick house)
- US assumes Russian silos can withstand 5,000 psi (example of ‘worst-case’ analysis)
- To destroy a silo this hard, a 300 kt warhead would have to land within 100 m

Silo-Based Missiles

Effect of missile accuracy

- Theoretically, missile survival is very sensitive to the miss distance D of incoming warheads
- An an example, assume
  - — 1,000 Minuteman silos are hardened to 2,000 psi
  - — Two 1.5 MT warheads are targeted to explode at ground level on each silo
- Computations predict
  - — If D = 300 ft, then 20 missiles survive (60 if 5,000 psi)
  - — If D = 500 ft, then 200 missiles survive (600 if 5,000 psi)

Sources of Systematic Error

- Gravitational field variations
- Atmospheric drag variations

Gravitational Field Variations

Some possible causes —

- Bumps on the Earth (mountains)
- Mass concentrations (masscons)
- Gravitational pull of the Moon

  (Motion of the Moon changes *g* by 3 ppm. An error in *g* of 3 ppm introduces a bias of 300 ft.)

The Earth's gravitational field is carefully measured over US and R (E-W) test ranges —

- US: Vandenberg to Kwajalein
- R: Plesetsk to Kamchatka and Tyuratam to Pacific

But wartime trajectories would be N-S over pole.

Atmospheric Drag Variations

Some possible sources —

- Jet streams
- Pressure fronts
- Surface winds
(30 mph surface wind introduces a bias of 300 ft.)

Density of the atmosphere —

- Is a factor of 2 greater in the day than at night
- Varies significantly with the season
- Is affected by warm and cold fronts

Data from military weather satellites and from models of weather over SU targets were reportedly used to update US warheads twice per day

Uncertainties on Silo-Based Missiles

Fundamental uncertainties

- Missile accuracy
- Warhead yield
- Silo hardness

Operational uncertainties

- System reliability
- Wind and weather
- Effects of other warheads (fratricide)
- Extent of ‘collateral damage’
  (‘digging out’ missiles creates enormous fallout)

Effects of Explosive Yield, Missile Accuracy, and Silo Hardness on Land-Base Missile Vulnerability

Probability of destroying ("killing") a missile silo: $P_K = 1 - e^{-K/f(H)}$

- A 10-fold increase of warhead yield Y increases the kill factor K by about a factor of 5.
- A 10-fold decrease in the warhead miss distance D increases the kill factor K by 100.
- For a kill factor of 20, a 10-fold increase in the silo hardness from 300 psi to 3000 psi reduces the probability of silo destruction from about 85% to about 35%.

Counterforce Capabilities

U.S. ICBMs:	K = 107,000
U.S. Trident II D5:	K = 475,000
Russia ICBMs:	K = 131,000
Russia SLBMs:	K = 9,500

Submarine-Based Missiles

Operational considerations

- Vulnerability depends on
  size of operational areas, ASW threat, counter-ASW capability
- Ability to survive
- US SSBNs are quieter than Russian SSBNs
  (but Russia is improving rapidly)
- US leads in anti-submarine warfare (ASW) capability
  and access to high seas
- Fraction of forces on-station
  (duration of patrols, time required for repairs)
- System reliability
- Effectiveness of command and control

Submarine-Based Missiles

Effective number of warheads (example) before New START

- United States

2688	[SLBM warheads}
x 0.75	[fraction typically on-station]
x 0.90	[estimated reliability]
= 1,814	[effective number of warheads]

- Russia

2384	[SLBM warheads}
x 0.25	[fraction typically on-station]
x 0.70	[estimated reliability]
= 447	[effective number of warheads]

These examples show that many factors *other than just the number of warheads* are important in comparing the effectiveness of nuclear forces.

Module 5: Nuclear Delivery Systems

Part 5: Nuclear Command and Control

Nuclear Command and Control – 1

C3I: Command, Control, Communication, Intelligence

Specific goals—

- Provide strategic and tactical warning
- Provide damage assessments
- Execute war orders from National Command Authority before, during, and after initial attack
- Evaluate effectiveness of retaliation
- Monitor development of hostilities, provide command and control for days, weeks, months

Nuclear Command and Control – 2

Some important aspects and implications —

- Organizational structure of command and control
- Available strategic communications, command, control and intelligence (C^3I) assets
- Vulnerability of strategic C^3I assets to attack

Alert levels — (Defensive Readiness Condition)

DEFCON 5 Normal peacetime readiness
DEFCON 4 Normal, increased intelligence and strengthened security measures
DEFCON 3 Increase in force readiness above normal readiness intelligence and strengthened security measures
DEFCON 2 Further Increase in force readiness
DEFCON 1 Maximum force readiness.

Nuclear Command and Control – 3

Satellite systems

- Early warning
- Reconnaissance
- Electronic signals
- Weather
- Communication
- Navigation

Response Times for Attack or Breakout

The Threat of Accidental Nuclear War – 20 Dangerous Incidents

1) November 5, 1956: Suez Crisis Coincidence

2) November 24, 1961: BMEWS Communication Failure

3) August 23, 1962: B-52 Navigation Error

4) August-October, 1962: U2 Flights into Soviet Airspace

5) October 24, 1962- Cuban Missile Crisis: A Soviet Satellite Explodes

6) October 25, 1962- Cuban Missile Crisis: Intruder in Duluth

7) October 26, 1962- Cuban Missile Crisis: ICBM Test Launch

8) October 26, 1962- Cuban Missile Crisis: Unannounced Titan Missile Launch

9) October 26, 1962- Cuban Missile Crisis: Malstrom Air Force Base

10) October, 1962- Cuban Missile Crisis: NATO Readiness

Source: www.nuclearfiles.org/kinuclearweapons/anwindex.html

The Threat of Accidental Nuclear War
20 Dangerous Incidents

11) October, 1962- Cuban Missile Crisis: British Alerts

12) October 28, 1962- Cuban Missile Crisis: Moorestown False Alarm

13) October 28, 1962- Cuban Missile Crisis: False Warning Due to Satellite

14) November 2, 1962: The Penkovsky False Warning

15) November, 1965: Power Failure and Faulty Bomb Alarms

16) January 21, 1968: B-52 Crash near Thule

17) October 24-25, 1973: False Alarm During Middle East Crisis

18) November 9, 1979: Computer Exercise Tape

19) June , 1980: Faulty Computer Chip

20) September, 1983: Russian False Alarm

21) November, 1983 Able Archer

21) January, 1995: Russian False Alarm (Norwegian research missile)

Source: www.nuclearfiles.org/kinuclearweapons/anwindex.html

January, 1995: Russian False Alarm

On January 25, 1995, the Russian early warning radar's detected an unexpected missile launch near Spitzbergen. The estimated flight time to Moscow was 5 minutes. The Russian President, the Defense Minister and the Chief of Staff were informed. The early warning and the control and command center switched to combat mode. Within 5 minutes, the radar's determined that the missile's impact would be outside the Russian borders.

The missile was Norwegian, and was launched for scientific measurements. On January 16, Norway had notified 35 countries including Russia that the launch was planned. Information had apparently reached the Russian Defense Ministry, but failed to reach the on-duty personnel of the early warning system.

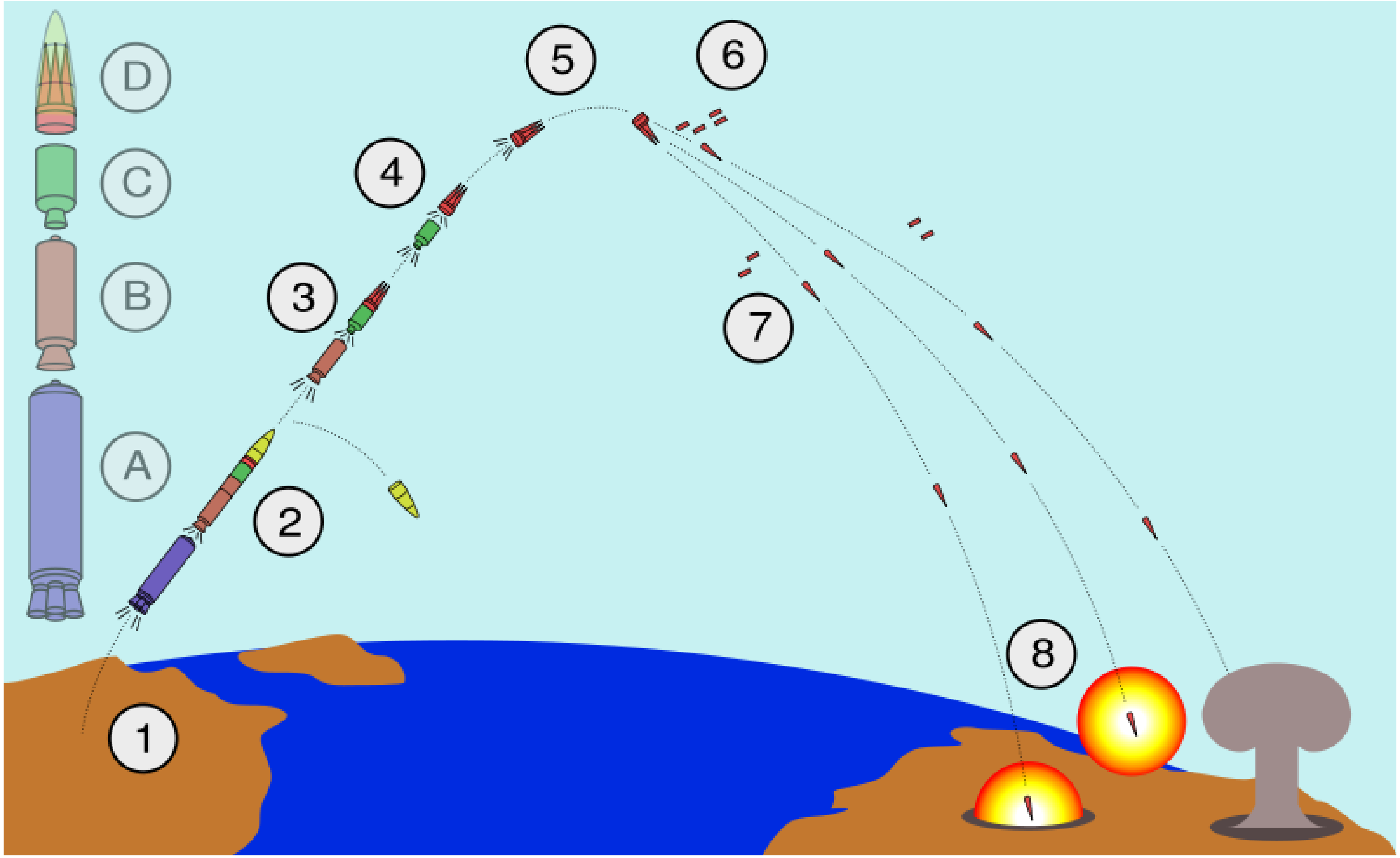
Possible Risk Reduction Measures

- Put ballistic missiles on low-level alert
- Reduce number of warheads on missiles
- Remove warheads to storage
- Disable missiles by having safety switches pinned open and immobilized
- Allow inspections and cooperative verification

Source: B. Blair, H. Feiveson. F. von Hippel, Taking Nuclear Weapons off Hair-Trigger Alert, Scientific American, November 1997

End of Module 5

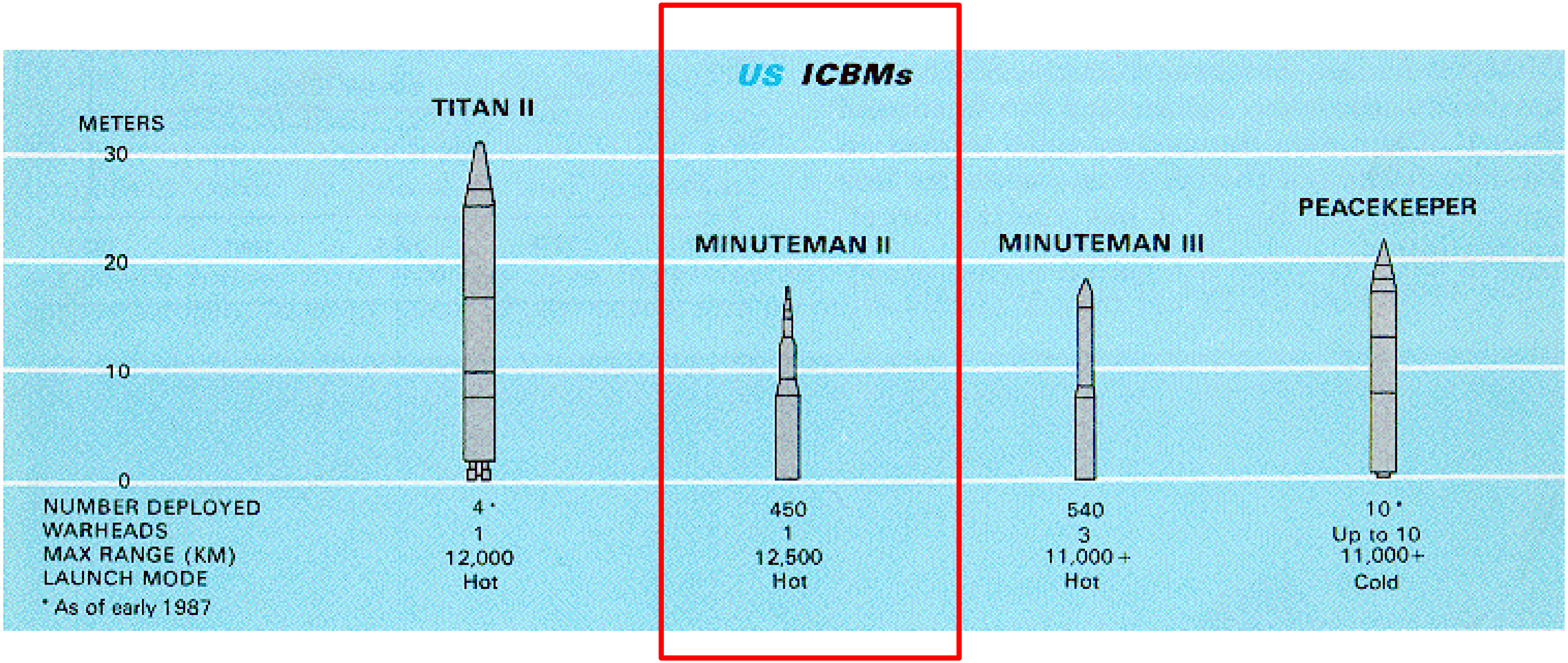
Flight of a MIRV'd ICBM (Schematic)



Flight of a MIRV'd ICBM (Schematic)

1. The missile launches out of its silo by firing its 1st stage boost motor (*A*).
2. About 60 seconds after launch, the 1st stage drops off and the 2nd stage motor (*B*) ignites. The missile shroud is ejected.
3. About 120 seconds after launch, the 3rd stage motor (*C*) ignites and separates from the 2nd stage.
4. About 180 seconds after launch, 3rd stage thrust terminates and the Post-Boost Vehicle (*D*) separates from the rocket.
5. The Post-Boost Vehicle maneuvers itself and prepares for re-entry vehicle (RV) deployment.
6. The RVs, as well as decoys and chaff, are deployed during backaway.
7. The RVs and chaff re-enter the atmosphere at high speeds and are armed in flight.
8. The nuclear warheads detonate, either as air bursts or ground bursts.

US ICBMs – 1



current land based
US ICMB

US and Russian SLBMs